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STATE OF NEW YORK

DEPARTMENT OF CONSERVATION

WATER RESOURCES COMMISSION

Hydrology of the Shallow Ground-Water Reservoir of the Town of Southold, Suffolk County, Long Island, New York

By

JOHN F. HOFFMAN

U. S. Geological Survey

Prepared by the

U. S. GEOLOGICAL SURVEY

in cooperation with the

NEW YORK STATE WATER RESOURCES COMMISSION

SUFFOLK COUNTY BOARD OF SUPERVISORS

and the

SUFFOLK COUNTY WATER AUTHORITY

BULLETIN GW-45

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HYDROLOGY OF THE SHALLOW GROUND-WATER RESERVOIR OF THE TOWN OF SOUTHOLD, SUFFOLK COUNTY, L. I., N. Y.

By

John F. Hoffman

ABSTRACT

The Town of Southold proper occupies 47 square miles of the North Fork, a peninsula extending 27 miles into the Atlantic Ocean from the northeastern end of Long Island, N. Y. Owing to the extensive withdrawal of ground water for irrigation in Southold, sea-water contamination of the ground-water reservoir is a potential problem. As sea water bounds the peninsula on three sides and underlies the shallow ground water at depth, overpumping the ground-water reservoir would sooner or later result in lateral or vertical salt-water encroachment, or both.

Conditions for growing potatoes are excellent in a major part of the Town. Precipitation has been sufficient to produce a good potato crop in nearly all of the last few years. However, supplemental irrigation has increased yields substantially during years of normal precipitation and has decreased crop losses in drought years.

Most, if not all, of the available fresh ground water of Southold is contained in glacial deposits which constitute the shallow ground-water reservoir. As the horizontal permeability of these deposits is greater than the vertical permeability and as these deposits are apparently underlain by layers of very fine sand or clay, the upward movement of salt water under the present pattern of withdrawal has not been evident, if it is occurring at all. Despite the fact that withdrawals have increased markedly in recent years, sea-water encroachment has been restricted thus far to nearshore areas of Southold where the altitude of the water table is less than 2 feet above sea level.

Natural replenishment of the ground-water reservoir is derived solely from precipitation that falls within the Town. However, only part of this precipitation reaches the reservoir, mainly because of losses by evaporation. Overland runoff losses, which are common in most hydrologic systems, are small owing to the gentle slope of the terrain and the highly porous soil cover.

The permissible perennial withdrawal from Southold's ground-water reservoir is difficult to establish because of the ever-present possibility of sea-water encroachment. The problem resolves itself into selection of a conservative rate of annual withdrawal that will prevent serious overdraft of the reservoir, both locally and areally, under prevailing conditions of recharge. Unless serious overdraft occurs, the fresh-water head probably will be sufficient to prevent the movement of sea water in large quantity into the fresh water-bearing beds. In this report, the permissible annual withdrawal has been conservatively established as equal to the estimated average replenishment during the consecutive 3-year period of least precipitation since 1826. The estimates indicate that about 30 percent of the average precipitation would replenish the water-bearing beds during such a 3-year dry period. On this basis, the water-bearing beds of Southold can be expected to yield perennially at least 7,000 million gallons per year or about 19 million gallons per day. Additional water may be obtained by temporarily "mining" ground water during brief periods of low replenishment; however, further study and closer evaluation of little known hydrologic and geologic problems of the Town are required before such "mining" can be practiced with impunity. Foremost among the problems requiring further study is the relationship of fresh ground-water storage to precipitation trends. A strong possibility exists that optimum conditions of storage during the present period of study may obscure the problems that will result from the reduced storage caused by long-term deficiencies in precipitation.

PURPOSE AND SCOPE OF REPORT

On the basis of data furnished by the New York Water Resources Commission (prior to February 1960 the Commission was known as the New York Water Power and Control Commission), it is estimated that in 1957 about 2,400 million gallons of fresh water was pumped from the glacial deposits which constitute the shallow ground-water reservoir underlying the Town of Southold. As the welfare of the entire population depends on an adequate local supply of ground water of good quality, it is important to know if the present (1958) extensive withdrawal for irrigation and other uses is bringing about conditions that would favor sea-water contamination of the ground-water reservoir.

This report is part of an overall and continuing appraisal of ground-water conditions on Long Island begun in 1932. The need for future management of Long Island's water supply was recognized during the early 1930's. Since that time a continuing island-wide investigation of ground water has been carried on by the U. S. Geological Survey in cooperation with the New York Water Resources Commission, the Nassau County Department of Public Works, the Suffolk County Water Authority, and the Suffolk County Board of Supervisors.

Work on a ground-water study of the Town of Southold was started by the writer late in 1948 in connection with fulfillment of thesis requirements for a Master's degree and was completed in 1952. Later it was decided to amplify the scope of the thesis into a more comprehensive report and to include some additional data which had become available up to 1957. Thus, the present report reviews data concerning the geology, hydrology, and ground-water conditions of Southold available up to the middle of 1957. The chief objectives have been to appraise the eventuality of sea-water encroachment, to evaluate recharge to the ground-water reservoir, and to offer recommendations for more complete investigation of the ground-water resources.

ACKNOWLEDGMENTS

The author wishes to acknowledge the cooperation of Mr. Harry Monsell, Superintendent of Public Works, village of Greenport, and the New York State Department of Conservation, Bureau of Marine Fisheries in furnishing data concerning the chloride concentrations of the waters of the Town of Southold. The field work for this report was greatly expedited by Mr. Monsell's making available to the Geological Survey much of the equipment and manpower under his jurisdiction.

GEOGRAPHIC FEATURES

The Town of Southold, referred to in this report also as Southold, is at the extreme northeast end of Long Island, occupying the eastern 21 miles of the North Fork, one of the two peninsulas that join the main part of eastern Long Island at Riverhead. Southold's total land area of 53 square miles comprises only slightly more than 3 percent of Long Island's total area of 1,373 square miles. This relationship is shown in figure 1. Included in the area of Southold are the 6 square miles of Fishers Island, Plum Island, and Robbins Island. However, these islands are not considered in this report.

Southold has a population density much below the average for Long Island, for it contains less than 0.1 percent of the Island's population (table 1). The village of Greenport contains slightly less than one-quarter of this population, making it the largest community in the Town of Southold. Summer vacationers and fishermen seasonally increase the population of the village of Greenport and the Town of Southold by approximately 50 percent.

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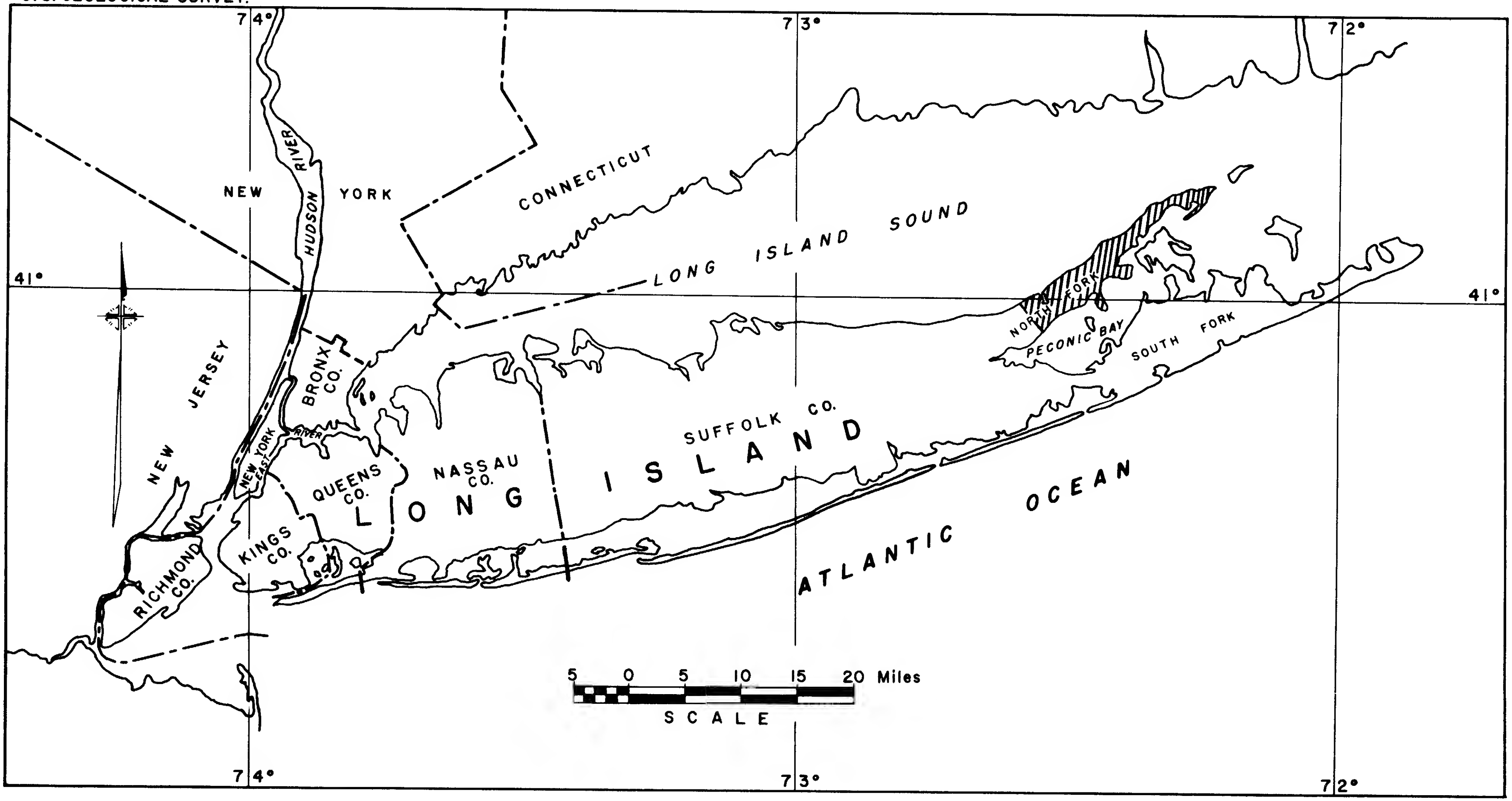

Figure 1.--Index map of Long Island, N. Y., showing the location of the Town of Southold.

Table 1.--Population of Town of Southold and village of Greenport, 1920-57

Year	Village of Greenport	Town of Southold 1/
1920	3,122	10,147
1930	3,062	11,669
1940	3,259	12,046
1950	3,028	11,484
1957	2,645	12,607

1/ Includes village of Greenport.

Southold's average annual air temperature is about 51°F (M. F. Woods, U. S. Geological Survey, written communication, 1941), ranging from the January average of 31°F to the July average of 69°F. The growing season, which usually extends from April 20 to October 29, is normally about 192 days long. Precipitation varies considerably from place to place in Southold. Based on records available up to 1950, precipitation ranges from about 45 inches at Cutchogue (51 years of record) and 37 inches at Orient (10 years of record), to 33 inches at Greenport (11 years of record).

According to Gustafson and Johnstone (1941) the Sassafras silt-loam soil, averaging about 3 feet in thickness, covers most parts of Southold. This soil is described as "light to light brown in color and only fairly well supplied with organic matter. Sassafras silt loam holds water and nutriments fairly well." Cultivation loosens this soil sufficiently so that during the spring and winter months a large part of the incident precipitation seeps into the ground. The Sassafras sandy loam, Haven loam, Plymouth sandy loam, and Dukes sand also have been identified in the Town, but they are unimportant because of their small areal extent (Gustafson and Johnstone, 1941). The Greenport clay, which occurs in the western part of Greenport, makes this section a relatively poor agricultural area and retards recharge to the underlying ground-water reservoir.

The Town's favorable climate and soil make it one of the major potato-producing areas of Suffolk County, which itself ranks high among the other potato producing areas in the Nation. Although the acreage under cultivation has been relatively constant since 1899, the main crop cultivated has shifted gradually from grain to potatoes. Of the 13,614 acres planted in vegetables in Southold in 1948, more than 76 percent was used for the cultivation of potatoes (U. S. Department of Agriculture, 1948).

Besides agriculture, the economy of Southold also depends to some extent on the summer tourist trade, the numerous oyster beds off the southern shore of the peninsula, and the fishing boats, both commercial and pleasure, that use its harbor facilities.

WATER UTILIZATION

Water for public supply, irrigation, and domestic use in Southold is obtained from the only source available -- ground water. In 1957 ground-water withdrawals for these uses amounted to an estimated 2,400 million gallons. This water comes solely from the glacial (upper Pleistocene) deposits which constitute the shallow ground-water reservoir as most, if not all, of the water stored in the deeper Magothy(?) formation of Late Cretaceous age may be salty, and very little is known about the water in the still deeper Raritan formation, also of Late Cretaceous age, underlying the area.

Methods of Withdrawal

More than 1,000 wells have been drilled, driven, or jetted into the water-bearing deposits underlying Southold. For the most part, these wells have steel casings ranging in diameter from 1¼ inches to about 12 inches and extend to depths ranging from a few feet to about 200 feet. Screens are a necessary part of well construction. These range in length from 2-foot well-point screens on domestic wells to screens 30 feet or more in major public-supply wells. An important part of the well construction is development, which involves the removal of the finer grained particles from around the screen. Were it not for development, many wells screened in unconsolidated material could be pumped only at very low rates.

Artificial ponds also are used as a source of irrigation water where the water table is less than about 8 feet below the land surface. These are common in the eastern part of Southold. Ponds generally average about 40 feet square and 6 feet deep, but may differ considerably from these dimensions according to individual needs.

Deep-well turbines are the most commonly used type of pump in Southold. Centrifugal pumps are used to a small extent where the suction lift is less than about 15 feet. A modification of the deep-well turbine pump that is coming into more popular use is the submersible pump. All the working parts of this type of pump, including the electric motor, are contained inside the well, and are submerged below the water level. Where small-capacity pumps are required, such as for household use, and the depth to water is beyond suction lift, jet pumps are commonly used.

Public Supply

Formerly, there were two public water supplies in Southold, the North Fork Water Co. and Village of Greenport Water Supply. However, in 1957 the facilities of the North Fork Water Co. were purchased by the village which

presently (1958) operates both systems. Besides supplying water for domestic and commercial use, these systems supply water for firefighting and other municipal requirements.

Annual withdrawals from wells of the North Fork Water Co. system, to serve 225 homes in the Town of Southold, have been relatively constant at about 20 million gallons. As shown in figure 2, annual withdrawals from the municipal system of the village of Greenport, to serve about 800 homes, have increased gradually from about 61 million gallons in 1932 to 150 million gallons in 1957. The peak annual pumpage of 167 million gallons was reached in 1955. Pumpage during the months of June, July, August, and September reflects in large degree the increased seasonal use for sprinkling and for the tourist population. It amounts to more than 40 percent of the annual withdrawal.

The water supplies for the North Fork Water Co. system are drawn from 4 wells at a pumping station located at the intersection of South Harbor Road and Route 25 (pl. 1). The village of Greenport currently (1958) operates three well fields. Two of these fields (stations 1 and 3) are located in the western part of Greenport less than half a mile apart. Another well field (station 2), located between stations 1 and 3, has been shut down since 1956 owing to the presence of undesirable concentrations of iron and bacteria in the water. The third active well field (station 4) is located in the eastern part of Greenport near the East Marion village line and about 1 mile east of stations 1 and 3.

Irrigation

Southold is one of the two most intensively irrigated Towns of Long Island, the second being the Town of Riverhead, immediately to the west. In 1957 approximately 1,900 million gallons, or about 79 percent of the total estimated annual ground-water withdrawal in Southold was used for irrigation. The irrigation withdrawal was made during a 107-day period starting in the middle of June and extending through October. The record maximum annual withdrawal for irrigation occurred in 1949 when an estimated 4,600 million gallons of water was pumped during the growing season.

Water for irrigation is pumped through portable aluminum pipe to oscillating sprinklers, which spray it in a circular pattern. A common type of sprinkler distributes about 15 gpm (gallons per minute) through each sprinkler head. Another type distributes 400 gpm through one sprinkler head.

The amount of water used and the frequency of application vary widely. Some farmers irrigate when the soil no longer cakes upon being squeezed. Others follow the recommendations of the Long Island Research Farm at Baiting Hollow, N. Y., and supplement the rainfall with enough water to insure the application of an average of 1 inch of water per week to the land. Still other farmers have little equipment and are short of manpower; consequently their irrigation procedures are adjusted to these limitations.

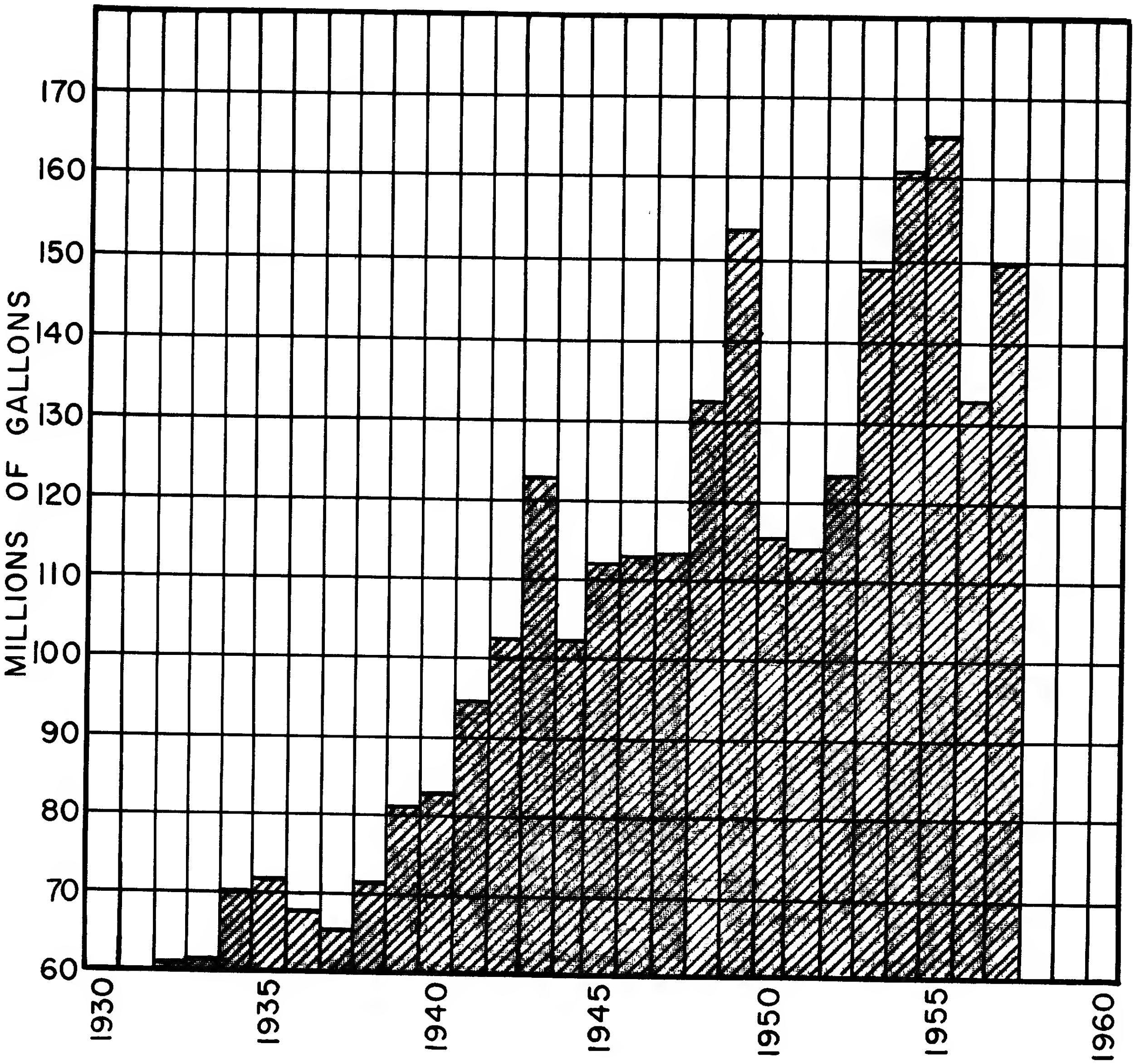

Figure 2.--Annual pumpage for village of Greenport Water Supply, 1932-57.

Domestic Use

About 9,000 persons in Southold are not served by a public supply and private domestic wells 4 inches or less in diameter constitute the source of supply. Based on an estimated daily water requirement of 100 gallons per capita, ground-water withdrawal for domestic use would amount to about 0.9 million gallons per day, or about 330 million gallons annually.

Method of Disposal of Used Water

Water pumped for household use in Southold generally is discharged to septic tanks and cesspools whence it returns to the water-bearing deposits. An exception to this practice is found in the village of Greenport, where sewage effluent is discharged, after treatment, directly to Long Island Sound.

Water used for irrigation in Southold is applied to crops by sprinkling, and most of the water probably is evaporated from soil and plant surfaces. At times, however, excessive amounts of water may be applied to the soil, and a part of the applied water will be returned to the water table. In general, probably only a small part of the water pumped for irrigation returns to the water-bearing deposits. Pumping for irrigation, therefore, results in a net loss from the ground-water reservoir.

GEOLOGY

The geology of Southold is closely related to the hydrology of the ground-water reservoir. Besides forming the medium in which the fresh water is stored, the glacial and older unconsolidated deposits that underlie Southold govern many of the factors affecting infiltration, recharge, and discharge. On the one hand, the permeable facies of these deposits provide conduits through which salty water may encroach inland, but on the other hand the impermeable facies form barriers against such encroachment. The vertical and lateral distribution of permeable and impermeable facies in these deposits do much to determine the position of the water level in the ground-water reservoir under given recharge-discharge conditions and thereby affect the depth at which salty water is first encountered in wells.

Physical Geology

The present topography of Southold is largely the result of marine and subaerial erosion of unconsolidated deposits of late Pleistocene age that were laid down by glacial ice and its melt water. The backbone of the Town consists of low hills of the Harbor Hill terminal moraine, which generally lie close to the north shore of the peninsula and in places end abruptly in precipitous cliffs facing Long Island Sound. The crest of this moraine is gently undulating, approaches sea level in some places, and extends eastward along the entire length of Southold. Its maximum altitude in both the eastern and western parts of the Town is about 100 feet above sea level. A glacial outwash plain slopes gradually southward from the base of the morainal hills to the tidal waters on the south shore of the peninsula where several embayments fringed with marshy areas form an indefinite shoreline (pl. 1).

Subsurface Geology

Relatively little is known directly about the subsurface geology of Southold, for most wells terminate at shallow depth in upper Pleistocene deposits. Only three deep wells, S189, S490 (V892), and S3123, have been drilled on the North Fork peninsula. Of these, two penetrated the Lloyd sand member of the Raritan formation and reached bedrock; the third well was drilled into the Magothy(?) formation above the Raritan. The log of well S189 is published in Bulletin GW-4 (p. 93-97) of the New York State Water Resources Commission and that of well S490 (V892) in a report by Veatch (1906, p. 330). As data from the three deep wells and other shallow wells suggest a general correspondence between the subsurface geology of Southold and that of the rest of Long Island, some estimate of the character of the various formations may be made by a review of Long Island's subsurface geology, which has been described in some detail by deLaguna and Perlmutter (1949).

The Raritan formation, deepest of the unconsolidated deposits on Long Island, rests unconformably on a basement of crystalline bedrock, which generally slopes at about 80 feet per mile in a southeasterly direction. The Raritan is composed of two members -- an upper clay member and a lower Lloyd sand member. The clay member beneath most of Long Island generally consists of beds of silty and solid clay and some sandy layers. The Lloyd sand member is predominantly coarse sand and some gravel, but is intercalated with thin layers of silt and clay. As the overlying clay member has a very low permeability, the water in the Lloyd sand member is generally confined under artesian pressure.

The Magothy(?) formation is considerably thicker than the underlying Raritan formation in most places on Long Island. It consists of layers of fine sand, silt, and clay interbedded with several zones of coarse sand and

gravel. Preglacial erosion of the Magothy(?) formation developed considerable relief on the upper surface. Consequently, the depth at which this surface is first penetrated by wells is quite variable. The water in the Magothy(?) formation is generally under artesian pressure but locally is unconfined.

The Jameco gravel, the oldest recognized glacial deposit underlying Long Island, generally rests unconformably on the Magothy(?) formation, but where erosion has removed the Magothy(?) it may rest directly on the Raritan or even on bedrock. The Jameco gravel is composed chiefly of coarse sand and gravel, but some lenses of clay and silt are present. Confinement by the overlying Gardiners clay causes the water stored in the Jameco to be generally under artesian pressure. Although extensive deposits of the Jameco are known to occur in western Long Island, the formation or its equivalent has not been yet (1958) identified in eastern Long Island or in Southold.

The Gardiners clay, an interglacial marine clay, is commonly composed of silty clay and some layers of coarse sand. The Gardiners clay is believed to be present in Southold but its thickness and areal extent are not yet clearly defined. In western Long Island, however, wells indicate that it underlies an area of considerable extent (deLaguna and Perlmutter, 1949).

Glacial deposits of late Pleistocene age mantle the older formations in practically all places on Long Island. They also form the present land surface and surficial deposits of Southold. Two types of materials of different geologic origin are recognized in the deposits -- till and outwash. Till is commonly a heterogeneous mixture of sand, clay, and boulders deposited from glacial ice. Generally it is poorly sorted, and the presence of clay, in some places, causes this material to have rather low permeability. In other places, the till is nearly free of clay and is quite sandy, and locally may have a high permeability. Outwash was deposited from glacial melt water and is moderately to well sorted. It is largely composed of sand and some gravel, and has a relatively high permeability. Stratification, however, and the presence of lenses of clay and silt interbedded with the sand and gravel usually cause the horizontal permeability of outwash to exceed the vertical permeability.

The estimated altitude and thickness of the various formations underlying Southold, listed in table 2 below, are based largely on the geologic contour maps assembled by deLaguna and Perlmutter (1949), and partly on the logs of wells S189, S490, and S3123.

Table 2.--Estimated altitude and thickness of stratigraphic units underlying Southold (after deLaguna and Perlmutter, 1949)

Age	Formation	Estimated altitude a/ of top of stratigraphic unit: Western part	Estimated altitude a/ of top of stratigraphic unit: Eastern part	Estimated average thickness (feet)
Pleistocene	Upper Pleistocene deposits	b/ 100	b/ 100	225
Do.	Gardiners clay	?	?	?
Do.	Jameco gravel c/	?	?	?
Cretaceous	Magothy(?) formation	-150	d/-208	350
Do.	Raritan formation			
	Clay member	-700	Above d/-387	100
	Lloyd sand member	-825	Above -400	150
Precambrian	Bedrock	-1050	Above -500	-

a/ In feet, with reference to mean sea level.
b/ Maximum altitude in Southold; minimum altitude is sea level.
c/ This formation, or its equivalent, as yet has not been positively identified in Southold.
d/ Based on the log of well S189.

HYDROLOGY

Natural recharge to Southold's shallow ground-water reservoir is derived solely from the infiltration of precipitation on the Town. Only part of the precipitation recharges the reservoir, for a sizable amount is returned to the atmosphere by evaporation and transpiration. Overland runoff is small, however, owing to the porous soil cover and the gentle slope of the terrain. Natural discharge takes place by ground-water outflow and evapotranspiration in marshy tracts in the near-shore zone. Ground-water outflow comprises spring discharge along the shore, which is visible mainly at low tide, and nearly continuous upward seepage in the bottoms of adjacent salt-water bodies.

Southold, because of its topography and division by tidal inlets (pl. 1), can be conveniently grouped into three separate or nearly separate hydrologic areas or units. This facilitates the understanding of discussions of the relationships of precipitation, evapotranspiration, runoff, and recharge to storage in the ground-water reservoir. The first and largest hydrologic unit considered, termed area 1 in this report, covers about 29 square miles and is bordered on the west by Mattituck Inlet and on the east by Hashamomuck Inlet (pl. 1). The villages of Mattituck, Cutchogue, Peconic, and Southold are included in this area. Another hydrologic unit, designated area 2, contains about 7 square miles and is bordered on the west by Hashamomuck Inlet and on the east by Orient Harbor. The village of Greenport and the hamlet

of East Marion are in this area. The third unit, termed area 3, is about 4½ square miles in extent. Orient Harbor forms the western limit and Orient Point, the eastern. The village of Orient and environs are included in this unit. A fourth area of about 7 square miles in the extreme western part of Southold is not discussed for lack of relevant data.

Precipitation

For this report precipitation studies have been made to estimate minimum rates of recharge to and storage in the ground-water reservoir during the period of precipitation record up through 1950. Comparison of present ground-water recharge and storage with the estimated long-term minimum recharge and storage gives insight into the possibility of sea-water encroachment under present conditions of ground-water withdrawal.

The closest gage to Southold having long-term precipitation records is that at the Battery in New York City, about 80 miles west of the west edge of the Town. Precipitation trends at gages in Southold with shorter records resemble those of the Battery gage, and for this reason the New York City records have been used as a long-term base. In Southold, standard 8-inch rain gages are located at Cutchogue, Greenport, and Orient, and precipitation records for these stations are considered representative for hydrologic areas 1, 2, and 3, respectively. Precipitation data for these gages are summarized in table 3. A similarity exists in the precipitation trend measured at these gages, but the amount of catch differs appreciably (table 3). Part of this difference may be attributed to an expected variation caused by local topography and may be due to gage exposure and location. It is not possible at this time to evaluate the accuracy of each gage, and therefore the precipitation measured at each was considered to be representative of conditions in its hydrologic area.

Comparison of water levels in wells with precipitation indicates that in Southold there is only a general relationship between the precipitation in any one year and contemporaneous ground-water levels. Although water levels during a year may decline markedly as the result of large deficiencies in precipitation (fig. 3), it is doubtful that such short term deficiencies would be a direct cause of significant sea-water encroachment. Consequently, precipitation records were analyzed by groups of years. Significantly, review of the precipitation records for Cutchogue shows that a 3-year term is the longest during which precipitation has been substantially below normal every year. Any period of 4 years or more was found to have at least 1 year of substantially above-normal precipitation. For Cutchogue this 3-year average, which was 39.32 inches, occurred during the period 1924-26 and is 87 percent of the average computed for a 52-year record (1899-1950) at Cutchogue. For New York City this 3-year average, which was 34.25 inches, occurred during the period 1862-64 and is 80 percent of the average computed for New York City's 125-year record (1826-1950). Relating the minimum precipitation at New York City to a base that is more convenient for purposes of comparison, it is 78 percent of the average for the 9-year period July 1941 to

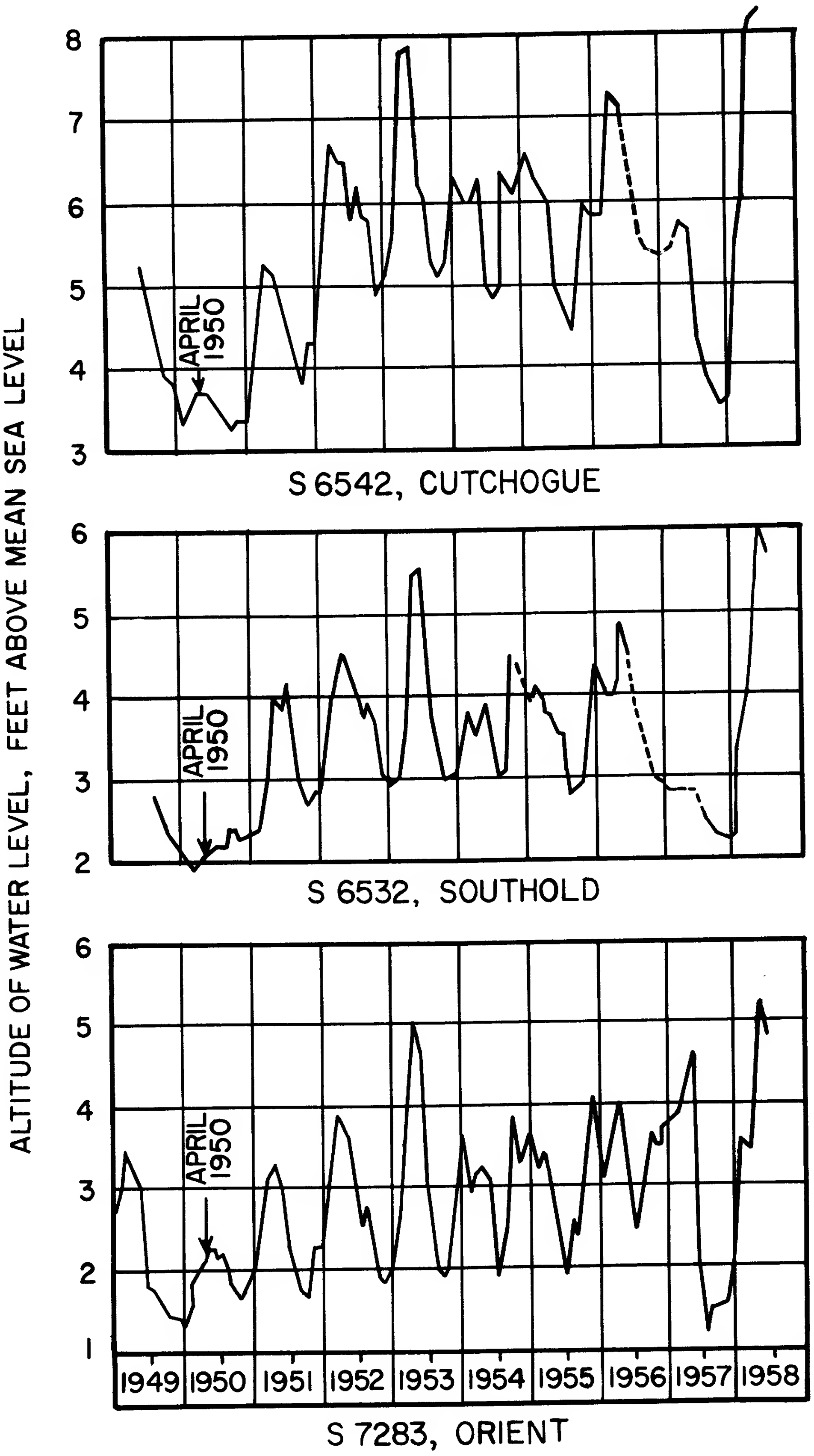

Figure 3.--Hydrographs of water levels in wells S6542, Cutchogue; S6532, Southold; and S7283, Orient.

Table 3.--Comparison of the average precipitation at gages located in Southold with the average precipitation at New York City for various selected periods up to 1950 (From records of the U. S. Weather Bureau)

Precipitation station	Period of record	Length of period (years)	Average precipitation, in inches												
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL
New York City	1826-1950	126	3.66	3.82	3.64	3.23	3.24	3.33	4.24	4.33	3.39	3.53	3.56	3.62	42.99
New York City	1899-1950	52	3.37	3.33	3.64	3.36	3.31	3.60	4.11	4.30	3.50	3.34	2.74	3.32	41.92
Cutchogue	1899-1950	52	4.06	3.50	4.32	3.92	3.26	3.46	3.46	4.10	3.55	3.45	3.85	4.27	45.20
New York City	July 1941-June 1950	9	3.65	2.69	3.90	3.09	4.39	3.72	4.45	4.44	3.25	2.84	3.73	3.59	43.75
Cutchogue	July 1941-June 1950	9	4.57	3.37	4.73	4.17	4.30	3.00	3.23	4.42	2.46	3.16	5.94	4.70	48.05
Greenport a/	July 1941-June 1950	9	2.80	2.03	3.06	2.89	3.20	2.09	2.51	3.72	1.78	2.17	3.90	3.23	33.38
Orient	July 1941-June 1950	9	3.52	2.75	3.60	3.08	3.54	2.09	2.46	3.84	2.06	2.19	4.59	3.58	37.30

a/ Records of the Village of Greenport Water Supply.

June 1950. On this basis the 3-year minimum average annual precipitation at Cutchogue (area 1) becomes 37.5 inches, at Greenport (area 2) 26 inches, and at Orient (area 3) 29 inches.

Evapotranspiration

Only part of the precipitation on land surface reaches the ground-water reservoir, for a sizable amount is returned directly by evaporation to the atmosphere. Evaporation also "pumps" water by capillarity from the soil zone and from zones of shallow water table and returns it to the atmosphere. A similar action occurs where the physiological processes of plants return water to the atmosphere by transpiration. The sum of these losses is known as total evaporation, or evapotranspiration.

Lack of essential data makes application of available formulas for estimates of evapotranspiration in Southold only very approximate. On the basis of studies in the north-central states, Meyer (1944) evolved a series of curves for estimating evaporation. These curves have as parameters the average monthly temperature and the average monthly precipitation. As such data are available for Southold, Meyer's curves have been applied to 3 years of contrasting rainfall conditions recorded at Cutchogue gage during the period through 1950. These years are 1908, the year during which the least annual precipitation occurred; 1948, the year during which the heaviest annual precipitation occurred; and 1949, a year during which the annual precipitation closely approached the long-term average. Using a watershed coefficient of 0.8 (Meyer, 1944, p. 457), the computed direct evaporation for 1908 was 12 inches; for 1948, 17 inches; and for 1949, 14 inches. Meyer concludes from his studies that the annual transpiration by agricultural crops in the North Central States is about 9 to 10 inches. For purposes of estimate in this report an annual transpiration rate of 9 inches was used. The estimated total annual evaporation (evapotranspiration) for Southold, the sum of direct evaporation and plant transpiration, computed for the 3 contrasting years ranged from 21 to 26 inches. In 1908 it was 21 inches, or 61 percent of the precipitation for that year; in 1948 it was 26 inches, or 42 percent of the precipitation; and in 1949 it was 23 inches, or 51 percent of the precipitation.

These estimates differ considerably from those of Spear (1921), who draws the generalization that the total annual evaporation on Long Island is about 17 inches.

Runoff

The absence of streams gives evidence that only a small part of the precipitation on Southold returns to the sea directly by overland runoff. Occasional heavy storms may cause some ephemeral streamflow, but in comparison with the amount of precipitation the overland runoff is small. However, ground-water outflow, or natural lateral outflow from the shallow ground-water reservoir, occurs along extensive seepage lines, or from numerous small springs along the shores of Southold, and through the floors of the bounding salt-water bodies. Such discharge probably constitutes the greater part of the total discharge of liquid water from the Town. Ground-water outflow is considered more completely under the subsequent section "Ground-water budget."

According to estimates in the Burr, Hering, Freeman report (1904) total runoff from Long Island as a whole amounts to 20 percent of drought-year precipitation (35 inches) and 33 percent of average-year precipitation (45 inches). Again, Leggette (as cited by Paulsen, 1940) has estimated that even during hurricanes direct overland runoff to Long Island streams is less than 5 percent of the storm precipitation. Qualitative evidence, such as that listed below, favors use of an estimate approximating Leggette's for the overland runoff in Southold:

1. The comparatively low moisture-retention capacity of the prevailing silty loam soil.

2. Excellent subsoil drainage of the silty loam of Southold by the underlying sand.

3. Retardation of overland runoff in the furrows of cultivated fields.

4. The flatness of the terrain.

5. The absence of visible runoff during most storms.

For a conservative estimate in this report, losses by overland runoff were considered to be about 10 percent of the annual precipitation.

Recharge

Recharge to the ground-water reservoir of Southold is the difference between precipitation and losses by evapotranspiration and overland runoff. From the preceding, it is estimated that about 70 percent of the annual precipitation during very dry years is dissipated by these losses. The remaining 30 percent, therefore, replenishes ground-water storage. According to Spear (1912), "for a dry period the amount of percolation would be . . . probably not greater than 17 or 18 inches, or 50 percent of an annual rainfall of 35 inches." During years having average precipitation, it is

estimated that about 40 percent of the annual precipitation replenishes ground-water storage. These estimates are somewhat lower than those of Spear's report (1912) wherein it is stated that recharge "for the Long Island watersheds during a year of average rainfall is probably not more than 50 percent of the mean annual rainfall or 22 inches."

The estimated average recharge at the rate of 30 percent of the 3-year minimum precipitation for hydrologic Area 1 would be about 11.3 inches per year, for Area 2 about 7.8 inches per year, and for Area 3 about 8.7 inches per year. On this basis, the estimated probable minimum annual recharge to the glacial deposits underlying the three hydrologic areas of Southold would be as given in table 4 below:

Table 4.--Estimated average annual recharge to the glacial deposits underlying Southold during the 3-year period of minimum rainfall

Hydrologic area	Locality	Land area (sq. miles)	Annual recharge		
			Million gallons	Million gallons per sq. mile	Million gallons per sq. mile per day
1	Mattituck Cutchogue Peconic Southold	29.2	5,750	197	0.54
2	Greenport	3.6	a/ 165	136	.37
	East Marion	3.1	420	136	.37
3	East Orient	2.4	365	152	.42
	West Orient	2.3	350	152	.42
1, 2, and 3		40.6	7,050	174	0.47
		Totals		Averages	

a/ On assumption that 75 percent of area is effective for recharge, owing to paving. Area of 2 square miles west of Chapel Lane, Greenport, is directly underlain by clay and is not considered in estimate.

Annual recharge to the ground-water reservoir during a series of years of normal precipitation might be 50 percent greater than that shown in table 4, or about 10,500 million gallons. This would be distributed as follows: area 1, about 8,600 million gallons; area 2, about 860 million gallons; and area 3, about 1,100 million gallons.

Some doubt exists as to the applicability of either Meyer's method or Spear's estimate to the Southold area, owing mainly to the lack of control data for the Town. Meyer's method needs sufficient climatologic data for checking the validity of the method and the magnitude of the watershed coefficient. Spear's estimate, on the other hand, generalized the results of a relatively few local observations in other parts of Long Island.

GROUND WATER

Occurrence and Storage

The available fresh ground water in Southold, for purposes of this report, is considered to be water, which occurs in the pore spaces of the upper Pleistocene glacial deposits. The three wells that penetrated the underlying Magothy(?) formation in Southold yielded salty water. Thus, there is a possibility that the water contained in this formation is salty beneath most of the Town. Few data are available relative to the salinity of water in the Lloyd sand member of the Raritan formation. In some parts of the Town the water may be fresh, but in other parts it is definitely salty. This conclusion is based on data for two deep wells that penetrated the formation. The first well, S490 (V892) a/, drilled in 1903 in Greenport for the village of Greenport, yielded a small amount of fresh water under artesian pressure, but this supply was considered insufficient for pumping (Veatch, 1906). Another well, S189, drilled in 1935 into the Lloyd sand member for the Long Island State Park Commission at Orient Beach State Park, about 10 miles to the east, reportedly yielded salty water from top to bottom and had to be abandoned (Hoffman and Spiegel, 1958).

The total amount of water stored in saturated deposits depends chiefly upon the volume of material containing the water and the porosity of this material. Only part of the stored water is recoverable; some of it is held by molecular attraction against the force of gravity. The ratio of the volume of water that can be drained by gravity from a unit volume of saturated material to the unit volume is termed "specific yield." The specific yield of water-bearing materials varies greatly and depends upon such factors as grain size, sorting, the orientation of constituent grains, and the compaction of the material. Evaluation of the results of a pumping test at irrigation well S7905 (see section on Movement), indicates that the glacial deposits locally have a specific yield of 0.17.

The water in the glacial deposits is largely unconfined and the upper limit of the saturated material in the unconfined deposits is marked by the water table. A map of the water table in Southold in April 1950 is shown in plate 1 (Lusczynski and Hoffman, 1950). The water table fluctuates markedly with changes in ground-water storage. The fluctuation in turn reflects

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a/ See well-numbering system described at end of report.

variations in recharge and discharge. This is evident from the hydrographs of wells S6532, S6542, and S7283, shown in figure 3. Also, from 10 years of water-level records for these and many other wells screened at shallow depth, it is evident that the water table in Southold was at a near-minimum stage in April 1950 for the period December 1948 to October 1956.

The shape and thickness of the shallow fresh ground-water body that overlies salty water beneath the Southold peninsula can only be conjectured, for very few deep-well data are available. Theoretically, if the contact between the fresh and the underlying salty water is considered to be sharply defined and a hydrostatic balance is considered to exist, the following formula can be written for the depth of the contact below sea level:

$$h = \frac{d_f}{d_s - d_f} \cdot h_f \qquad (1)$$

where h = the depth below sea level to a selected point on the fresh water-salty water interface,
h_f = the height above sea level of the water table directly above the selected point,
d_f = the density of the fresh water, and
d_s = the density of the salty water.

This relationship, which is sometimes referred to as the Ghyben-Herzberg ratio, is shown in an idealized cross section through a peninsula in figure 4. An actual cross section through the Southold peninsula at Cutchogue showing the profile of the water table in April 1950 is given in figure 5. The resemblance between the idealized profile of the water table in figure 4 and with the actual one shown in figure 5 is quite apparent.

The density of Southold's uncontaminated fresh ground water is close to 1.000. The density of the bay and ocean water bounding the Southold peninsula differs from place to place, depending on the point of sampling. The density of samples from the embayments collected by the U. S. Geological Survey and by the New York State Bureau of Marine Fisheries have ranged from 1.019 to 1.025. In certain embayments where large volumes of ground water are discharged and become more or less trapped, the density of the water may be as low as 1.010. However, if the salty water underlying the fresh ground water of the Southold peninsula is considered to have the maximum density of 1.025, then for every foot of fresh water above sea level about 40 feet of fresh water exists in below-sea-level storage. For a minimum density of salty water of 1.010 the ratio becomes 1:100. It is known that the contact between the fresh and salty water, at least in the case under consideration, is not sharply defined, and that a transitional zone, termed "zone of diffusion," exists. The dissolved solids and chloride in the water in this zone gradually increase in concentration toward the salty-water side. For example, in 1957, data concerning the zone of diffusion were obtained in the village of Greenport, located in hydrologic area 2. Here, a well point was driven into glacial sand and gravel to a depth of 70 feet. The altitude of land surface at the site was about 10 feet above mean sea level, and that of

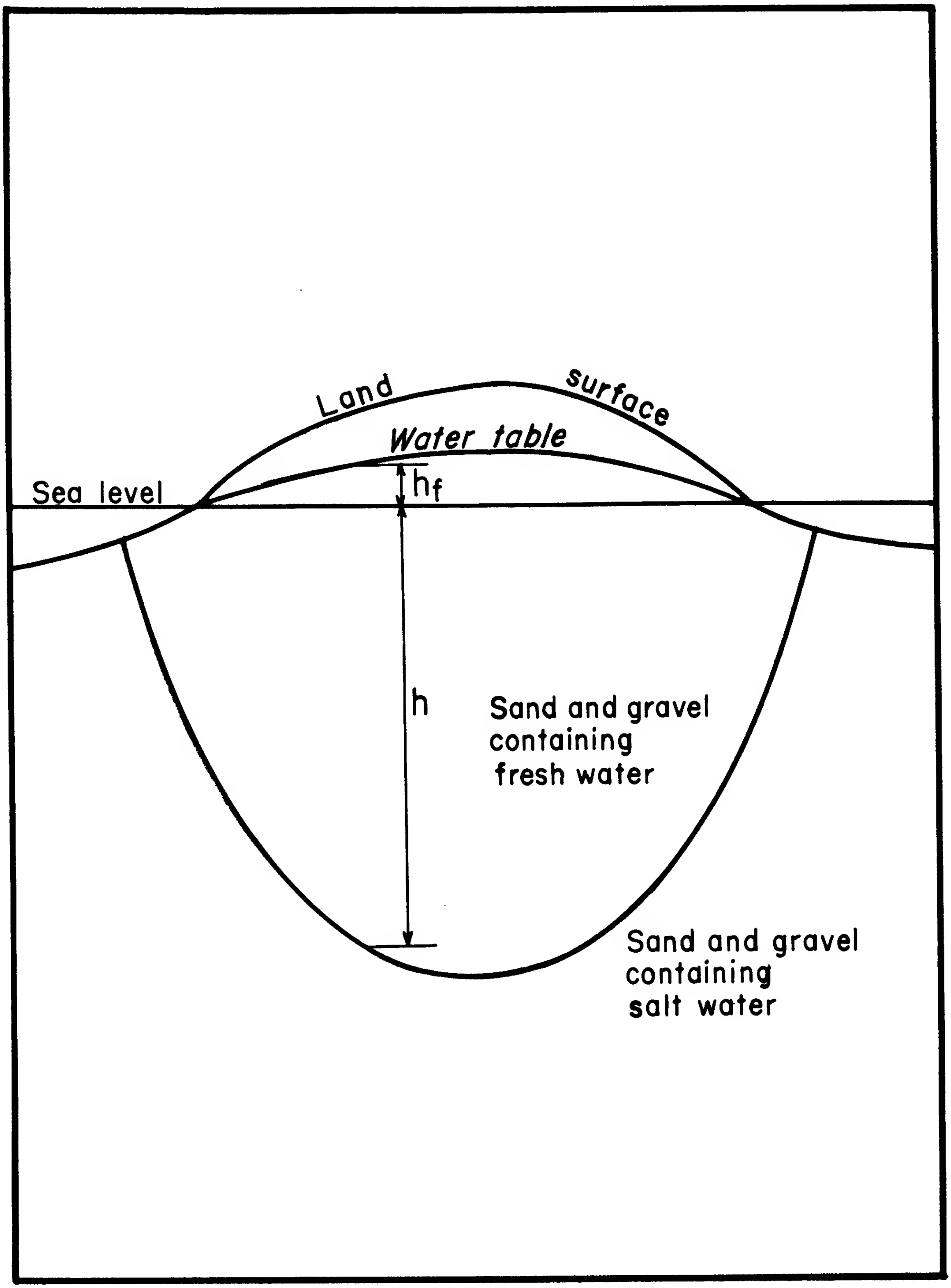

Figure 4.--Idealized cross section of a peninsula showing the relation of fresh and salt water according to the Ghyben-Herzberg principle.

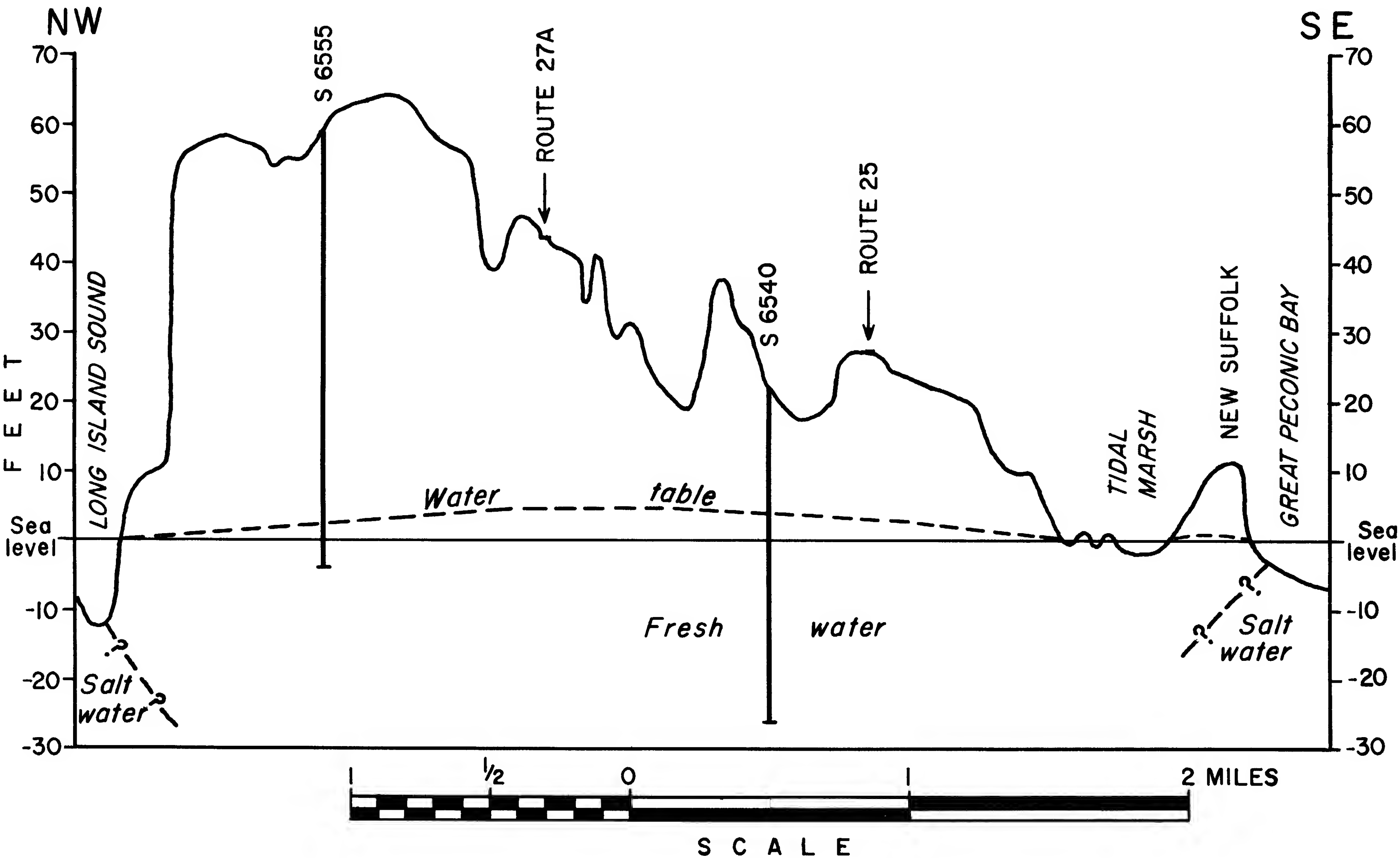

Figure 5.--Profile of the water table through the Southold peninsula at Cutchogue, April 1950.

the water table was about 1.1 feet above mean sea level. Water samples were taken about every 10 feet and analyzed for chloride concentration. The data are given below:

Depth of well screen below land surface (feet)	Chloride concentration (ppm)
33-36	82
44-47	332
54-57	510
58-61	6,800
67-70	12,500

The maximum normal chloride concentration of shallow ground water of Southold is generally estimated to be about 25 ppm (Hoffman and Spiegel, 1958). At the Greenport site chloride concentrations down to a depth of 57 feet may represent residual contamination from a break in the sanitary sewer in about 1950 or from the disposal of salty water about 500 feet from the site during a dewatering operation of many years ago. Another possibility is that the chloride concentrations may represent a part of the zone of diffusion. The density of a water sample from a depth of 42 feet was 1.000 and from a depth of 70 feet was 1.021. According to the Ghyben-Herzberg principle, the fresh water-salty water contact should be 48 feet below sea level, or 58 feet below land surface. Thus, there is a reasonable correspondence between observed conditions and the theoretical relationship.

As ground water is in motion (fig. 6), Hubbert (1940, p. 924-26) suggests that the hydrostatic relationship assumed by the Ghyben-Herzberg formula although originally determined empirically, gives approximately correct results at low hydraulic gradients. At higher gradients Hubbert suggests that its use is incorrect. Also, a recent appraisal of the relationship between fresh water and the underlying salty water in southwestern Nassau County (Perlmutter, Geraghty, and Upson, 1959) has led to the modification of the Ghyben-Herzberg formula (1), to read as follows:

$$Z = \frac{d_s}{d_s - d_f} \cdot h_s - \frac{d_f}{d_s - d_f} \cdot h_f \qquad (2)$$

where Z = altitude, in feet, of a point on the fresh water-salt water interface,

d_f = density of fresh water,

d_s = density of salt water,

h_f = altitude, in feet, of the water level in a well terminated in fresh water of density d_f, at or near the contact, and

h_s = altitude, in feet, of the water level in a well terminated in salt water of density d_s, at or near the contact.

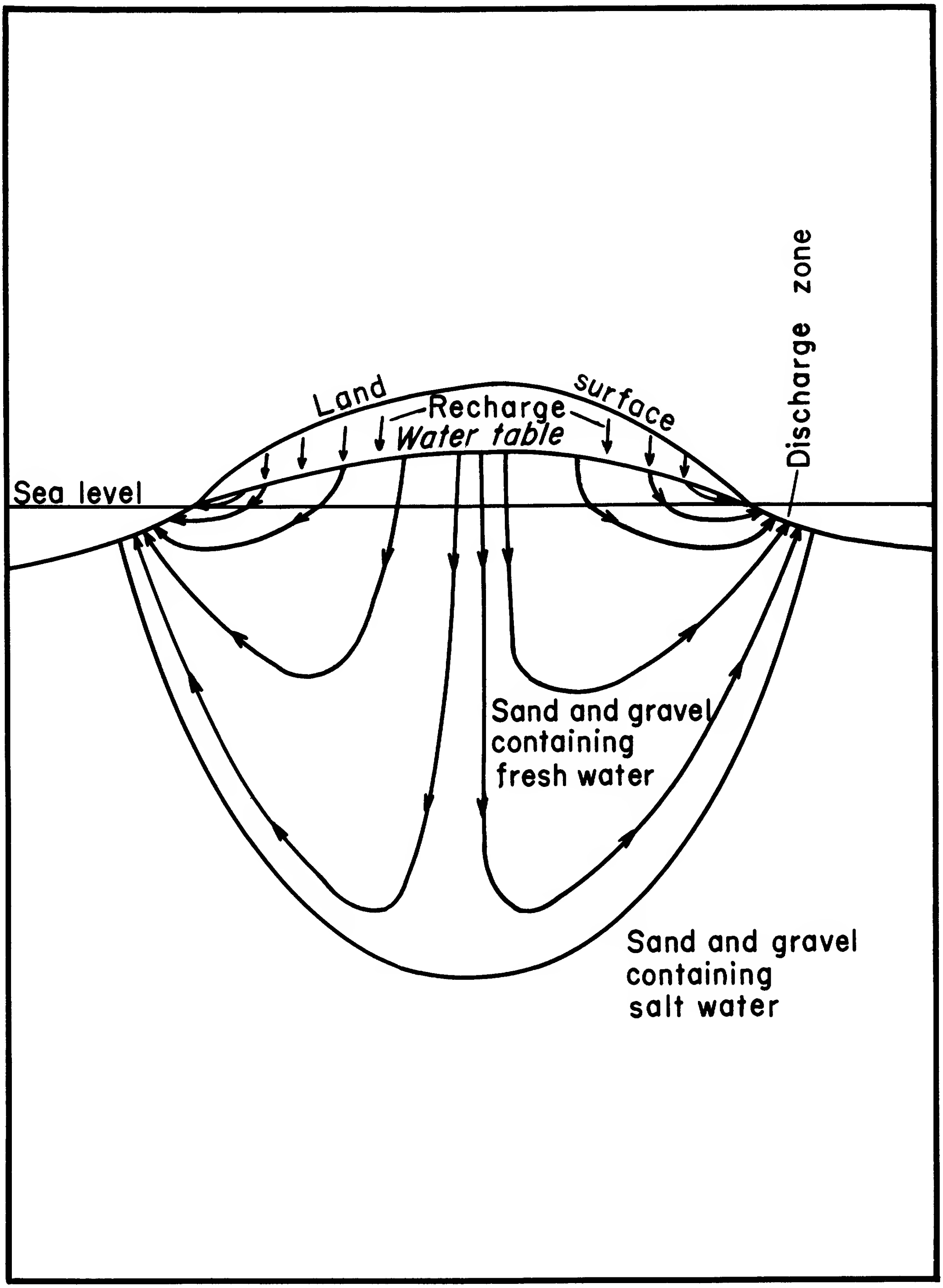

Figure 6.--Idealized cross section of a peninsula showing the natural movement of ground water in the vertical plane.

Much conjecture still exists about the actual relationship between the fresh and salty water at depth. The principal unknowns concern (1) volumetric and dimensional changes of the zone of diffusion, (2) volumetric and dimensional changes of the overlying fresh-water lens under varying conditions of ground-water recharge and discharge and for various short-term and long-term stages of the water table, (3) the distribution of salinity and density of the water stored in the zone of diffusion, and (4) any fluid movement or interchange that might take place within the zone of diffusion.

If fresh-water storage is considered to conform according to the Ghyben-Herzberg principle, for a ratio of 1:40 and a specific yield of 0.17, the fresh-water storage in the upper Pleistocene glacial deposits of the three hydrologic areas of Southold in April 1950 would approximate 83,000 million gallons. The breakdown of the estimate by hydrologic areas is shown in table 5.

Table 5.--Estimated fresh ground-water storage in the glacial deposits of Southold, in millions of gallons, April 1950

Hydrologic area	Location	Storage above sea level	Storage below sea level	Total storage
1	Mattituck Inlet, Mattituck to Peconic Lane, Peconic	1,300	52,000	54,000
	Peconic Lane, Peconic to Hashamomuck Inlet, Southold	400	16,000	16,400
	Subtotal	1,700	68,000	70,000
2	Chapel Lane, Greenport to Gull Pond Road, Greenport	40	1,600	1,600
	Gull Pond Road, Greenport to Causeway, East Marion	110	4,400	4,500
	Subtotal	150	6,000	6,100
3	West Orient to 1½ miles east of Main St., Orient	90	3,600	3,700
	East Orient	80	3,200	3,300
	Subtotal	170	6,800	7,000
	Total (rounded)	2,000	81,000	83,000

The estimated average annual recharge of 10,500 million gallons from the infiltration of precipitation previously discussed in the section on "Recharge" is equivalent to slightly more than one-eighth of the estimated volume of storage in the shallow ground-water reservoir in April 1950.

Major changes in ground-water storage on Long Island, N. Y., roughly follow a cumulative departure curve for precipitation at New York City. Figure 7 shows the comparison between the mean annual water level in the 14 selected wells in central Long Island and the cumulative departure curve for precipitation from 1826 to 1950 at New York City. The mean monthly water level in the 14 wells differed by less than about 2 feet from the mean annual water level for any one year in the period of observation. As climatic conditions in Southold are approximately similar to those of other parts of Long Island, ground-water storage in the shallow reservoir is assumed to follow qualitatively a trend somewhat similar to that shown in figure 7. Comparison of the departure curve and the average water levels in the 14 selected wells indicates that ground-water levels on Long Island and in Southold probably did not approach a long-term minimum during 1950. If the relationship shown in figure 7 is considered to hold throughout the period shown, water levels were at a minimum, for the period 1826 to 1950, sometime between 1852 and 1860. Few, if any, water-level data are on record for any area between 1852 and 1860. Therefore, storage determined for Southold on the basis of water levels in April 1950 (see table 5), although representing a near-minimum for the period, December 1948 to October 1956, cannot be considered to be a long-term minimum. During the period 1948-58, the rate of recharge to the ground-water reservoir varied appreciably. The rate was very high during 1948 when precipitation approached record highs, and very low during an extended dry period in the growing season of 1949. Heavy withdrawals for irrigation during the dry period caused water levels to reach a marked low in early 1950.

During more recent years, water levels in most wells in Southold approached minimum stages in the latter part of 1957 as the result of below-normal precipitation and recharge, and heavy withdrawals for irrigation. Heavy precipitation during late 1957 and early 1958, however, caused these levels to approach record to near-record highs in the spring of 1958. This is particularly evident in the hydrographs of S6532, S6542, and S7283 shown in figure 3.

Movement

The movement of water within the shallow ground-water reservoir is important to the fresh ground-water supply of Southold and to the potential impairment of its quality by sea-water encroachment. From an areal standpoint, the rate of ground-water movement is governed by the permeability of the aquifer in the direction of flow and by the factors that determine the hydraulic gradient. The permeability depends on the characteristics of the geologic medium through which the water moves and on the properties of the

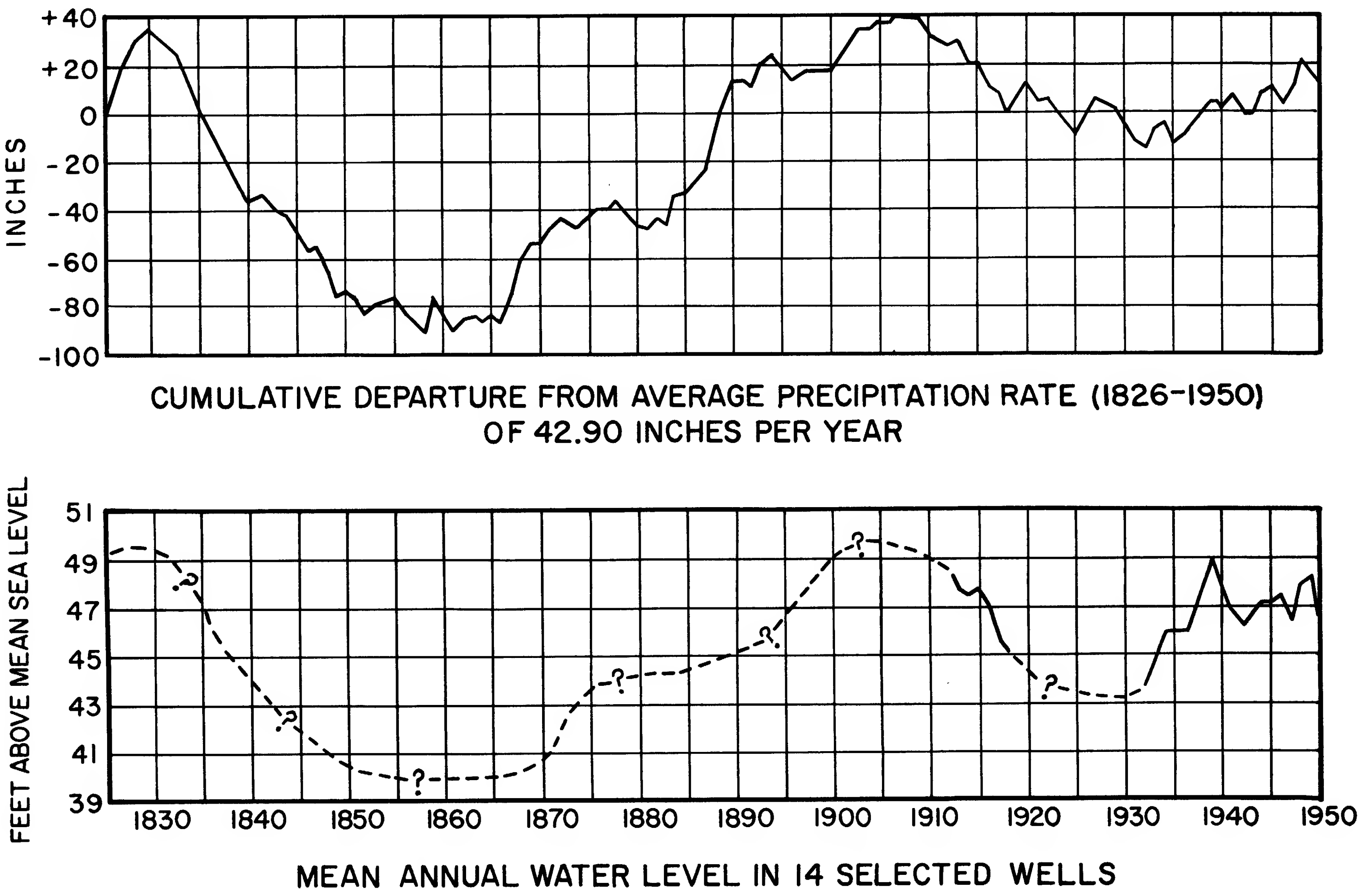

Figure 7.--Comparison of the cumulative departure from mean annual precipitation at New York City and the mean annual water level in 14 selected wells on Long Island.

water itself, particularly temperature and density. Variations in the physical character of the sediments constituting the ground-water reservoir of Southold have resulted in large differences in the permeability. Differences in temperature and concentration of dissolved salts in the water change the viscosity and density of the water and have a similar effect. As a result, the average permeability of the reservoir is not easily determined. In problems involving sea-water contamination, the local permeability of the sediments in the areas of heavy withdrawal is sometimes more important to the problem than the overall average permeability.

One method of determining the permeability of an aquifer is by means of pumping tests, or aquifer tests. These have been described by Theis (1935), Wenzel (1942), and Ferris (1949), among others. Using some of the methods of analysis, a coefficient of permeability is obtained directly. However, in the case of the Theis nonequilibrium formula, the transmissibility of the entire thickness of the aquifer is obtained. This is equal to the coefficient of permeability multiplied by the thickness of the aquifer.

The evaluation of a test at irrigation well S7905, north of the town of Southold, during which the well was pumped at about 325 gpm for 100 hours, indicates that the coefficient of transmissibility of the saturated glacial deposits in this area is about 200,000 gpd (gallons per day) per foot. Although the thickness of the saturated deposits cannot be established definitely, an estimate can be made from the log of the well. From this the saturated thickness is known to be greater than 50 feet, but probably less than 200 feet. Therefore, the coefficient of permeability may range between 1,000 and 5,000 gpd per square foot.

Evaluation of one aquifer test gives a knowledge of the hydraulic characteristics of only a comparatively small volume of sediments. This coverage may be extended throughout Southold, however, by comparing the specific capacities of many other wells in the Town with that of well S7905. The specific capacity of a well is computed by dividing the rate at which a well is pumped, in gallons per minute, by the maximum resultant drawdown, in feet. Although the quantity obtained is a unit of gallons per minute per foot of drawdown (gpm per ft), it is quite commonly referred to by the numerical value only. The specific capacity of well S7905 is 27 gpm per foot. Specific capacities for 77 other wells in Southold that were pumped at more than 100 gpm range from 7 to 67 gpm per foot, and the range is distributed as follows:

Range in specific capacity (gpm per ft)	Wells investigated	
	Number	Percent
40 or more	11	14
30 to 39	15	20
20 to 29	35	45
10 to 19	15	20
Less than 10	1	1
Total	77	100

Correlation of the specific capacity and the pumping rate of these wells shows a considerable scattering of the plotted points. Most of the specific capacities were determined from 8-hour well-capacity (yield) tests. At the end of 8 hours of pumping, the drawdown in well S7905 had reached more than 90 percent of the total drawdown for a 100-hour period of pumping. Assuming this to be true for most of the 77 wells under consideration, the scattering of points is probably due to variations in the hydraulic characteristics of the saturated deposits. Although a number of factors preclude any precise extrapolation, the data suggest that the transmissibility of the glacial deposits underlying Southold ranges from values somewhat less than 200,000 gpd per foot to values somewhat greater. Further consideration of this will be given in a later section concerning the "Ground-Water Budget."

The hydraulic gradient in areas where natural conditions prevail is related to the lithology, size, and shape of the ground-water reservoir, the precipitation pattern, and the proximity to and the direction from a regional "sink" where the continuous discharge of ground water can take place. In Southold such a "sink" is formed by the salty-water bodies that bound the Town. Pumping wells and evaporation from ponds and marshy areas can alter the hydraulic gradient locally and also affect the direction of the ground-water movement. Based on an evaluation of the water table for April 1950 as shown in plate 1, the maximum gradient evident is about 4 feet per mile. During times of maximum storage this gradient would probably be greater.

The relation of the factors involved in the rate of ground-water movement, expressed in units used by the U. S. Geological Survey, is as follows:

$$V = \frac{PI}{7.48\theta} \qquad (3)$$

where V = velocity, in feet per day,

P = permeability of the deposits in the direction of flow, in gallons per day per square foot of aquifer, under a hydraulic gradient of 1 foot decline in head for each foot of travel, at 60° F,

I = the hydraulic gradient, in feet per foot, and

θ = porosity, which is dimensionless.

For example, the rate of ground-water movement in the shallow ground-water reservoir underlying Southold, based on a permeability of 5,000 gallons per day per square foot, a hydraulic gradient of 4 feet per mile, and a porosity of 1/3, may be as much as 1½ feet per day.

The direction of horizontal movement of ground-water in Southold is at right angles to the water-table contours and is radially away from a series of highs (pl. 1) in the water table to the surrounding salty-water bodies. The role played by shoreline irregularities in governing the direction of ground-water movement is evident from plate 1. Owing to these irregularities, ground water may move from north to south in the northern part of the Town and from south to north in the southern part. Similarly, on points or necks, the movement may be to the east or to the west.

Precise information concerning the natural vertical movement of ground water in Southold is still lacking. Vertical movement through the ground-water reservoir is probably somewhat similar to the idealization shown in the cross section of figure 6. The water recharged in the inland highs follows longer flow paths than the water recharged in nearshore areas. The latter is probably discharged at or just beyond the shoreline. This idealization assumes a homogeneous, isotropic aquifer (one in which water moves with equal facility in all directions). The paths of ground-water movement are altered by the presence of layers of silt, clay, and cemented sand. Where such layers occur in Southold, the actual flow pattern may be considerably distorted from the idealization shown.

Water moves toward a pumped well in the manner shown in figure 8. When a well is pumped, two gradients influence the path of flow. One is caused by the presence of a natural regional "sink," and the other is caused by the local "sink" formed when the well is pumped. The resultant vertical flow pattern in the ground-water reservoir is shown in figure 9. Water particles close to the well move at a rate greater than those farther away. As the distance from the pumped well increases, the effect of the natural gradient on a particle of water becomes greater and diverts a greater amount of flow from a direct path toward the well. At still greater distance, the influence of the natural flow pattern is equal to that set up by the pumped well and a ground-water divide is created. Beyond this divide the effect of the natural flow predominates, although the flow paths are distorted. As a result of this combination of influences, the water level in a pumped well may be below sea level locally without causing movement of sea water toward the pumped well.

Ground-water budget

Water storage in the ground-water reservoir is a function of the more basic variables of recharge and discharge that constitute the ground-water budget. Changes in the rate of recharge, the rate of discharge, or both result in changes in ground-water storage. Fluctuations of water levels in wells screened immediately beneath the water table indicate these changes in storage. Decreased recharge resulting from below-normal precipitation may result in a shrinkage in the volume of fresh water in storage and cause salty water to move inland and upward. Ground-water withdrawal by pumping from wells at a rate in excess of reservoir recharge would have the same end result. Increased recharge from above-normal precipitation has the opposite effect. However, as soil-moisture conditions and consumptive losses vary with the season of the year, precipitation trends do not necessarily directly reflect trends in ground-water storage.

Figure 3 shows the marked effect that evapotranspiration has on ground-water storage. In most years storage is at a minimum during the late summer and fall and at a maximum during the spring. Even in summers of above-normal precipitation, interception of rainfall by plant and soil surfaces

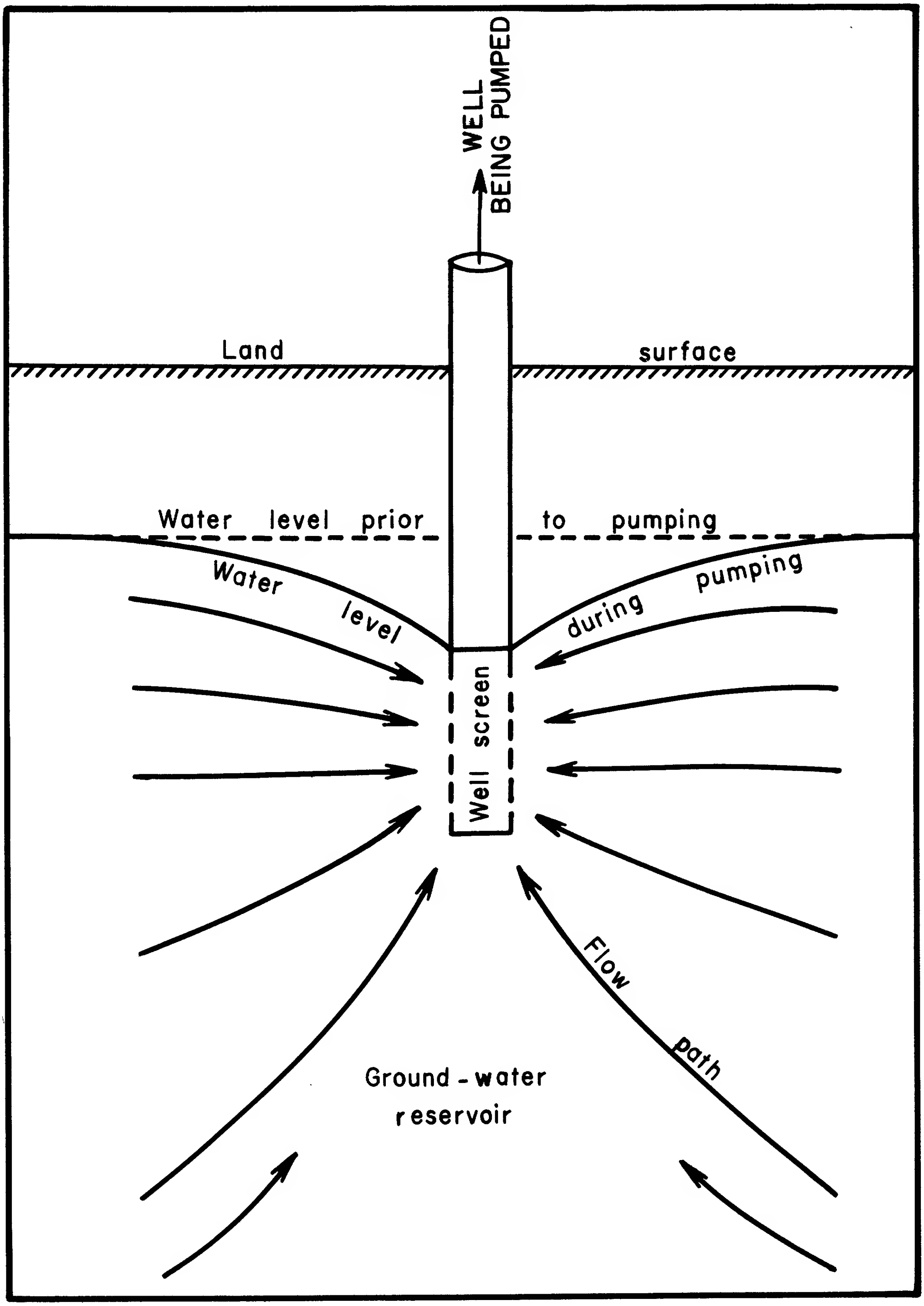

Figure 8.--Idealized cross section showing the movement of ground water toward a well being pumped.

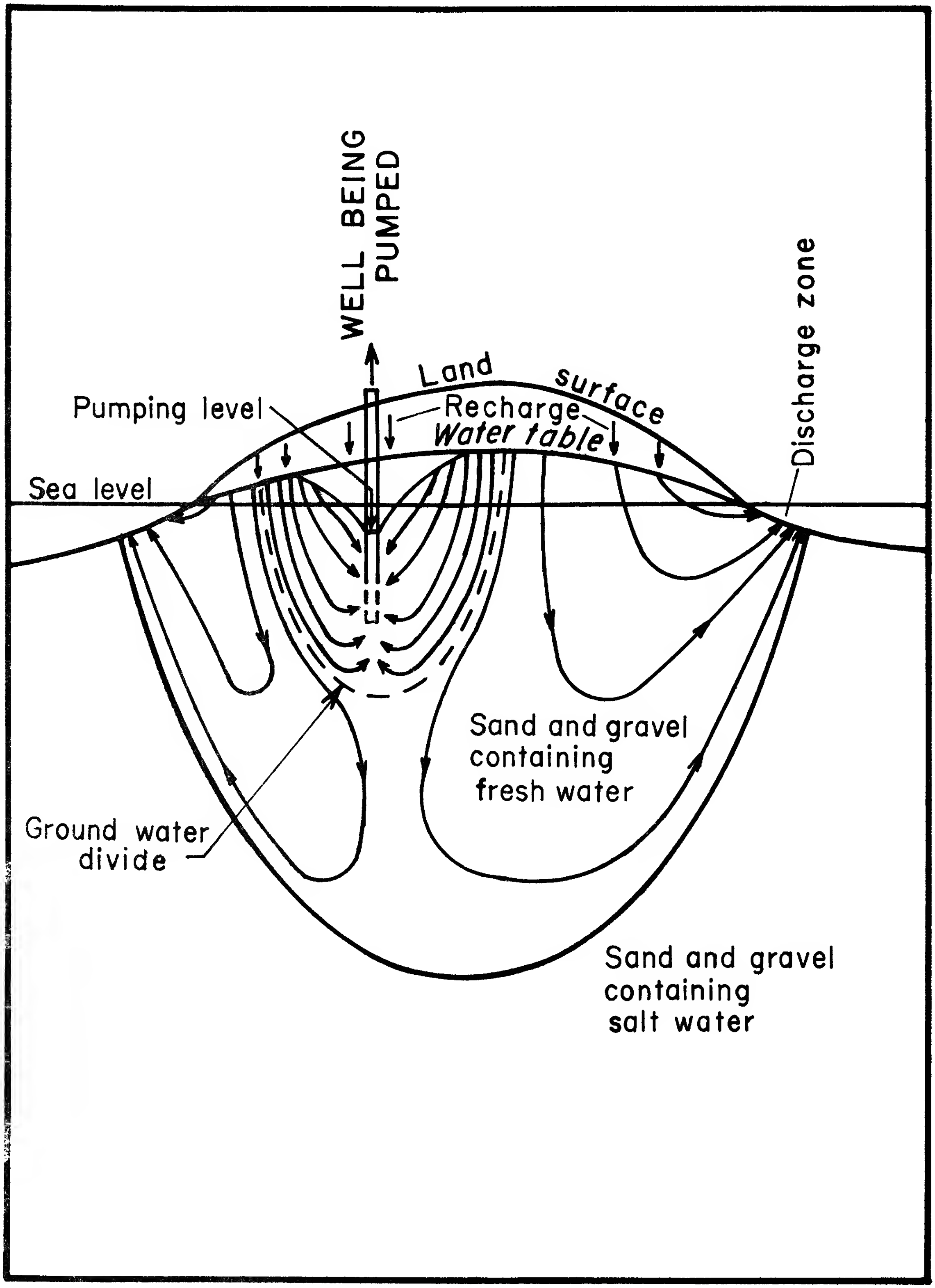

Figure 9.--Idealized cross section of a peninsula showing vertical movement of ground water around a well being pumped.

usually prevents appreciable recharge to the ground-water reservoir. Rainfall which seeps into the topsoil replenishes the moisture deficiency of the root zone. Water in storage in this zone is tapped by plants and returned to the atmosphere by transpiration, or is raised through the interstitial spaces in the soil to the surface by capillarity and evaporated. During late fall, water consumption by plants and direct evaporation diminish. Thus, precipitation in this period can replenish the ground-water reservoir more effectively. When the resultant recharge exceeds discharge in the form of lateral outflow and evaporation, water levels in wells begin to rise. Storage increases until evaporative and vegetative losses reduce ground-water recharge to the point where the depleting effects of these losses plus those of lateral outflow and pumping predominate. Water levels in wells then start to decline.

The net natural discharge from the ground-water reservoir by lateral outflow to the surrounding salt-water bodies and by evaporation from marshy areas probably ranges from 2,500 to 6,000 million gallons annually. This is based on a rate of recharge to the ground-water reservoir of at least 7,000 million gallons a year (see table 4) and annual withdrawals for irrigation and other consumptive uses ranging from 1,000 million gallons to 4,500 million gallons. If the recharge to and discharge from the ground-water reservoir followed the same pattern exactly each year equilibrium would be established. Under such circumstances there would be little difficulty in evaluating the ground-water budget on the basis of the recharge-discharge relation shown below:

$$R = D + \Delta S \qquad (4)$$

which may be written as:

$$P - \text{climatologic losses} = (U + e + D_w) + \Delta S \qquad (5)$$

where R = recharge,
D = discharge,
ΔS = change in storage,
P = precipitation incident upon land area,
U = lateral underflow,
e = evaporation from the ground-water reservoir exposed in marshy areas, and
D_w = net discharge from wells.

Certain conditions are thought to exist in the problem at hand which preclude a simplified consideration of the ground-water budget. The complexity arises not out of shortcomings in the theory but because sufficient data on the unknown factors are not available. These factors are discussed below.

Recharge to the ground-water reservoir has been determined earlier in this report on the basis of precipitation less climatic losses. The estimate of lateral underflow and evaporation from marshy areas in a preceding paragraph has been made on the basis of recharge in the consecutive 3-year period experiencing least precipitation since 1826 and a range in the withdrawal of ground water. As a steady-state condition was assumed, the time sequence of events in the approach could be ignored.

During most years precipitation is above the minimum value and both climatic conditions and withdrawals for irrigation vary widely. In a year of average precipitation recharge to the ground-water reservoir may be 3,500 million gallons more than that in a year experiencing below average precipitation. As previously discussed, recharge during years with the same annual precipitation may vary widely. Moreover, all the recharge may not reach the zone of saturation during the calendar year in which the precipitation took place. Some might be stored on land surface as snow and not reach the water table until after the Spring thaw. Some might be retained in the zone of aeration and not reach the water table in the year being budgeted. If the year in question has been preceded by a series of very dry years, the amount of water retained in the zone of aeration at the start of the year is at near-minimum. During the year a larger proportion of the recharge may be stored temporarily in the zone of aeration than if the preceding years were wet years.

After recharge has reached the water table, changes in the rate of accretion to fresh-water storage are assumed to be indicated by changes in the position of the water table. Implicit in this assumption is the consideration that such changes in storage take place above sea level. According to the Ghyben-Herzberg principle, however, storage in a lens of fresh water floating on salt water is divided into above- and below-sea level components. Theoretically, a change in fresh-water storage above sea level would counterbalance a change of at least forty times the amount in storage below sea level. In the case of Southold Township the fine sand, silt, and clay, which are thought to underlie the area would inhibit any rapid expansion or contraction of fresh water storage below sea level. However, as these materials are permeable to some extent, it is not unreasonable to assume that changes in the position of the water table would at least partly indicate a transfer of storage. The volume of recharge not going into storage would of course be discharged as lateral underflow or be evaporated from marshy areas. Such a consideration suggests the possibility that the low point to which the water levels in wells decline annually (fig. 3) lies in the surface of a more or less "permanent" lens of fresh water which is recharged at a minimum but more or less constant rate of recharge. Rates of recharge for relatively short periods in excess of the amount necessary to sustain this storage would tend to produce transient effects in the storage above sea level. However, the influence of precipitation trends throughout a longer period may modify the volume and shape of this "permanent" lens.

Evaluation of a ground-water budget for an aquifer consisting of a lens of fresh ground water floating on salt water is possible only when adequate data are in hand. These data are more complex than for areas where only fresh water is involved and where the sediments are homogeneous, the direction of the ground-water flow in cross-sectional view essentially is parallel to the water table, and the recharge-storage relationship of the aquifer is well-defined by the water levels in wells. In addition to the hydrologic data discussed earlier in the report, information concerning the relationship of the rate of change in volume of both above- and below-sea level storage with the rate of accretion to the water table should be in hand. Also, the relationship of this latter factor to precipitation throughout selected periods is necessary for computing losses by natural discharge.

A check of the order of magnitude of the lateral underflow may be made by application of Darcy's law as reannotated by Ferris (1949):

$$Q = TIW \qquad (6)$$

where T = transmissibility of the aquifer, in gallons per day per foot,
I = hydraulic gradient, in feet per foot, and
W = length, in feet, of trace in a horizontal plane of the vertical surface through which flow takes place and at which the gradient I exists.

On the basis of a transmissibility of 200,000 gallons per day per foot determined from the aquifer performance test at well S7905, a hydraulic gradient of 2 feet per mile, and a aggregate distance of 50 miles for the trace of the vertical surface through which flow takes place and at which the indicated gradient is assumed to exist, the average annual outflow is estimated at about 7,300 million gallons. Comparison of this amount with the values for the natural discharge described in the preceding pages suggests that the average transmissibility of the shallow deposits of Southold Township is less than 200,000 gpd per foot. Owing to the complex interrelationship between the flow pattern and the permeability of the deposits in the direction of flow and the lack of data, only approximate quantitative significance can be attributed to such a comparison.

SEA-WATER ENCROACHMENT

The deleterious effects of sea-water contamination on the fresh-water supplies of coastal areas are almost too obvious to mention. If present in fairly large concentration, salty water impairs the taste of drinking water, destroys the utility of water for irrigation, and corrodes metallic surfaces. Magnesium and calcium salts of the contaminating sea water increase the hardness of a water supply and increase soap consumption and costs by retarding the lathering action of soap. In addition, these salts form boiler scale. In extremely high concentrations, salt contamination can make a water supply unfit for human consumption, for industrial use, or for irrigation.

A typical analysis of sea water off the coast of Long Island is given in table 6.

Table 6.--Typical analysis of sea water off the coast of Long Island, N. Y. (after Burr, Hering, Freeman, 1904)

Constituent	Parts per million	Percent of total solids
Sodium chloride a/	26,430	80.4
Magnesium chloride a/	3,150	9.6
Magnesium sulfate	1,783	5.4
Calcium sulfate	1,330	4.0
Silica	120	.4
Calcium carbonate	56	.2
Magnesium carbonate	Trace	-
Iron oxide	Trace	-

a/ In this same report the chloride-ion concentration given for samples of sea water collected at various locations around Long Island ranged from 10,000 to 20,000 ppm.

Sodium chloride constitutes about 80 percent of the dissolved solids of sea water in the Long Island area and magnesium and calcium salts almost 20 percent.

Well water having a chloride concentration in excess of 500 ppm (parts per million) is not satisfactory for most uses. Although water having a chloride concentration as high as 500 ppm or even higher is not harmful to the human body, chloride concentrations in excess of 250 or 300 ppm impart a salty taste to the water. Tabulated below are the maximum chloride concentrations desirable for various uses (Hoffman and Spiegel, 1958):

Table 7.--Allowable chloride concentrations in water for various uses

Use	Maximum desirable chloride concentration (parts per million)	Source
Public supply	250	U. S. Public Health Service
Irrigation	100 to 1,260*	California State Water Pollution Control Board Publication No. 3, "Water Quality Criteria"
Carbonated beverages	250 **	Do.
Food-equipment washing	250 **	Do.
Sugar making	20 **	Do.
Textile processes	100 **	Do.
Paper making:		
Groundwood pulp	75 **	Do.
Soda pulp	75 **	Do.
Kraft pulp	200 **	Do.

* Varies with type of crop.
** Recommended threshold or limiting concentration.

Sea-water contamination of ground water, resulting in higher than normal concentrations of chloride, can take place by (1) natural landward migration of the zone of diffusion between fresh water and salty water in the formation, (2) sea-water inundation of low-lying shoreline areas as a result of high tides and storm winds, or of high winds alone, and (3) the pumping of a well situated close to a zone of diffusion at such a rate that salty water is drawn into the well.

At present, the nature, direction, and rate of movement of salty water toward the pumped wells in Southold are not completely known. Some possible ways by which salt-water encroachment may occur are illustrated in figures 9, 10, and 11.

In figure 10 the water is considered to be stored under hydrostatic conditions similar to that described by the Ghyben-Herzberg ratio (see section on "Occurrence and Storage"). The reduced head resulting from the lowering of water level around the pumped well cannot balance the head of the salty water at the fresh water-salty water contact, and salty water moves toward the well. Cessation of the pumping theoretically permits the water to move back to an equilibrium condition. Neither action is instantaneous, however, owing to the slow movement of ground water and the need for the flushing of water ahead of the advancing front. This slow response is demonstrated by the hydrograph of well S7283 in figure 3. The water level in this dug well is occasionally depressed to a position lower than 2 feet above sea level for relatively long periods during the irrigating season. Theoretically, with the 1:40 ratio, the fresh water-salt water contact should be less than 80 feet below sea level; yet nearby wells screened at this depth yield water of low chloride concentrations. This is because, as shown in figure 9, short-term pumping may not change the natural movement of ground water enough to establish a gradient from the salty water to the fresh water during pumping. Encroachment, therefore, would not occur even if the water level in the pumped well were below sea level. With extensive ground-water withdrawal and long-term pumping, the ground-water divide shown in figure 9 may extend to the zone of diffusion and salty water may be drawn toward the pumped well.

The important controlling feature in the movement of salty water toward pumped wells is the subsurface geology. Where the zone of diffusion and salty water are in or below material of low permeability, the salty water moves toward a pumped well at a very slow rate. If the layers of low permeability form a very tight, continuous seal, serious sea-water encroachment may occur only when the cone of depression of the pumped well has expanded to the shoreline as shown in figure 11, or when a sufficiently high gradient has been established across the layers of low permeability. If the layers of low permeability are not continuous, are thin, or have been breached, perhaps by erosion during glacial time, encroachment may come largely from beneath. Electrical-resistivity measurements and examination of cuttings from drilled wells in Southold suggest that layers of fine sand and silt interbedded with lenses and layers of clay do occur at varying depths. Additional test drilling and geophysical exploration will be needed to establish a more complete knowledge of the lithology of the deposits underlying the shallow ground-water reservoir of Southold.

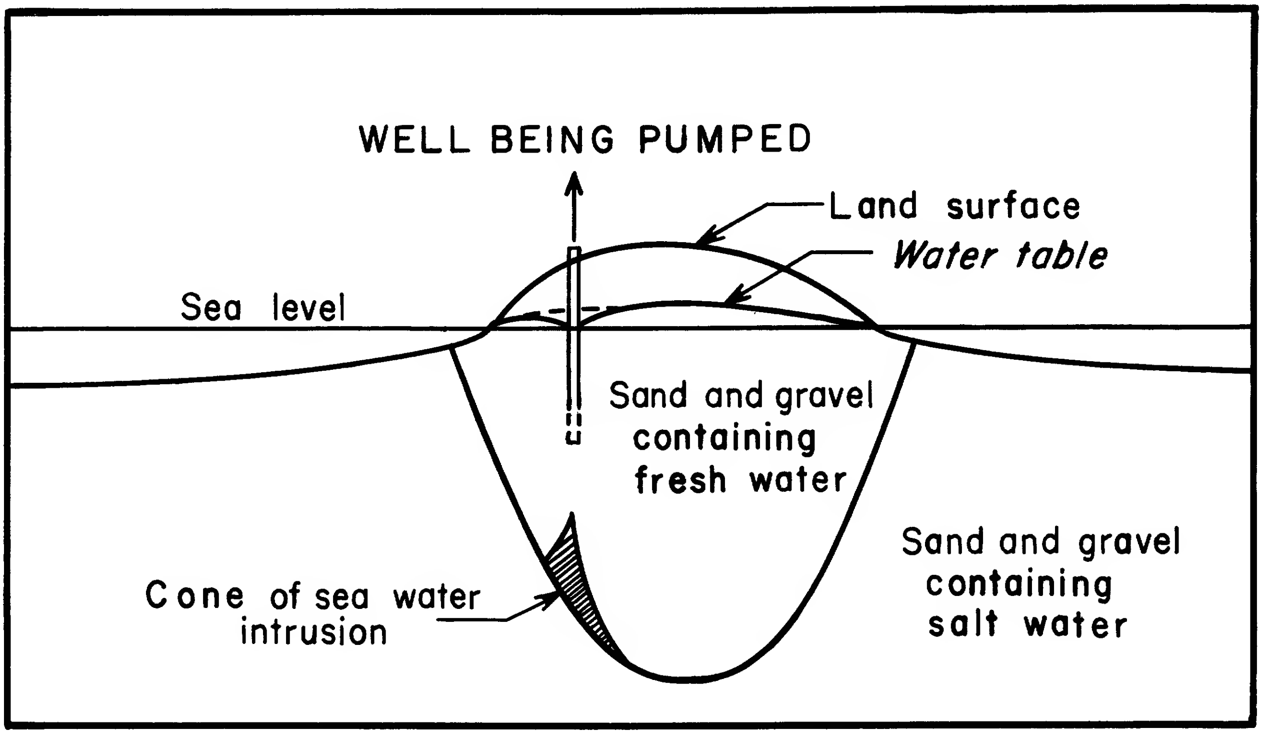

Figure 10.--Vertical sea-water encroachment caused by pumping.

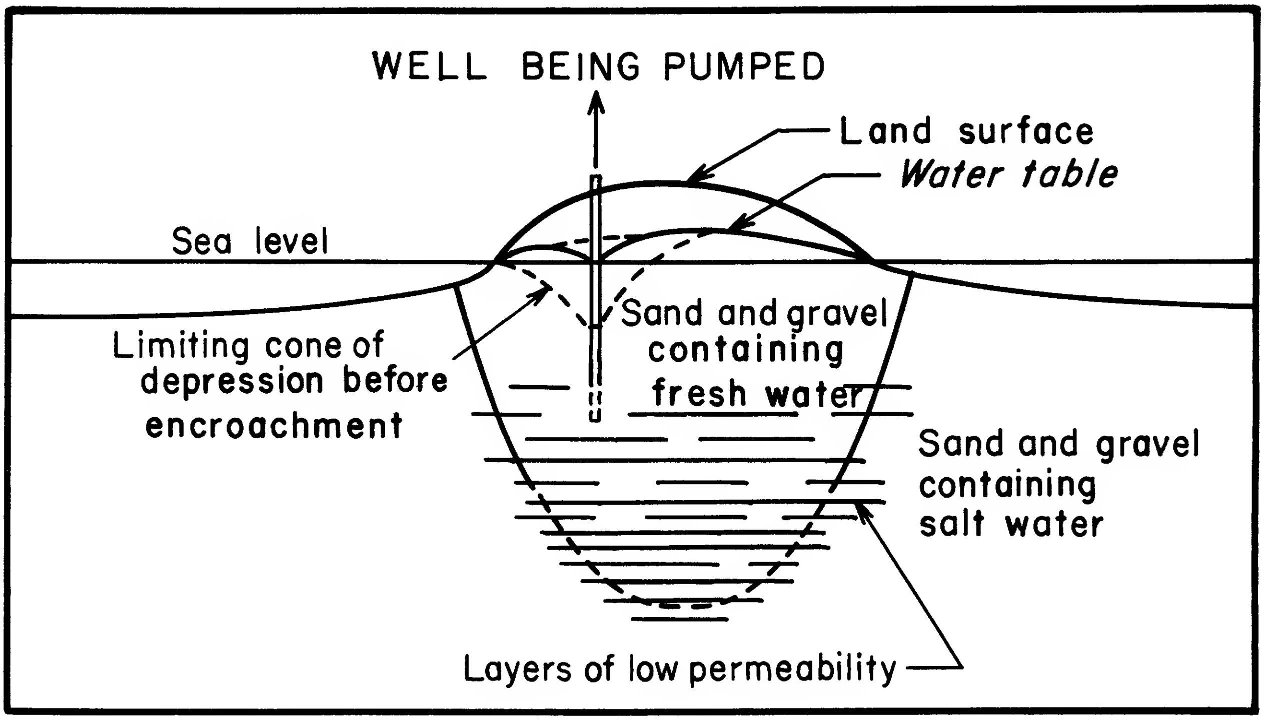

Figure 11.--Effect of layers of low permeability on the encroachment of sea water.

Contamination by sea water has caused some of the unusually high chloride concentrations at a number of individual wells and certain irrigation ponds in Southold -- at the villages of Orient, Greenport, Southold, Nassau Point, and Peconic (Hoffman and Spiegel, 1958). These well locations, shown in figure 12 and plate 1, are reviewed in the following sections.

Orient area

Contamination of wells and irrigation ponds by sea water is in evidence in the vicinity of Orient (hydrologic area 3), an intensively farmed and irrigated area of about 4½ square miles at the eastern tip of the North Fork (fig. 12).

This area is almost entirely surrounded by the sea, and salt marshes fringe the shoreline portions of some of the outlying farms. Occasionally, hurricanes and other severe storms cause tidal waters to flood the low-lying lands. Because of the proximity of sea water and of the low fresh-water head, it is reasonable to assume that the fresh ground-water body is thin and that salty water occurs at a relatively shallow depth. Moreover, because of the absence of industry in the area, the distance of the sampling points from the roadways, and the low population density, widespread above-normal chloride concentrations in the ground water cannot be attributed to industry, highway maintenance (spreading of salts to reduce dust or melt ice and snow), or cesspools. Inasmuch as the use of fertilizer in other intensely farmed areas of Suffolk County has produced chloride concentrations of less than 75 ppm in the ground water and presumably would produce a comparable effect in this area, concentrations above 75 ppm cannot readily be attributed to fertilizer. Sea-water contamination is the obvious remaining choice.

High chloride has been recorded in some of the irrigation ponds in Orient. The highest recorded is 5,810 ppm in pond P-6 on September 30, 1948. Samples taken from this pond on later dates showed a fairly consistent decrease to 60 ppm on June 26, 1953. During the summer of 1948 heavy and continuous withdrawals lowered the pond level and caused salty water to move into the pond either from the adjoining tidal inlet or from the ground beneath, or both. After 1948, draft from this pond ceased and the water gradually freshened. Most of the samples from the other ponds had chloride concentrations of 90 ppm or more -- for example, 100 ppm in P-4 on October 11, 1948; 124 ppm in P-5 in August 1949; and 202 ppm in P-9 on July 7, 1952. The water level in all these ponds is only 1 to 3 feet above sea level, and the ponds are near salt marshes or tidal inlets. The high chloride may be due in part to occasional sea-water inundation; or, more likely, to heavy withdrawals. The heavy withdrawals lower the pond level and allow the adjacent salty surface water to move in or underlying salty water to move upward.

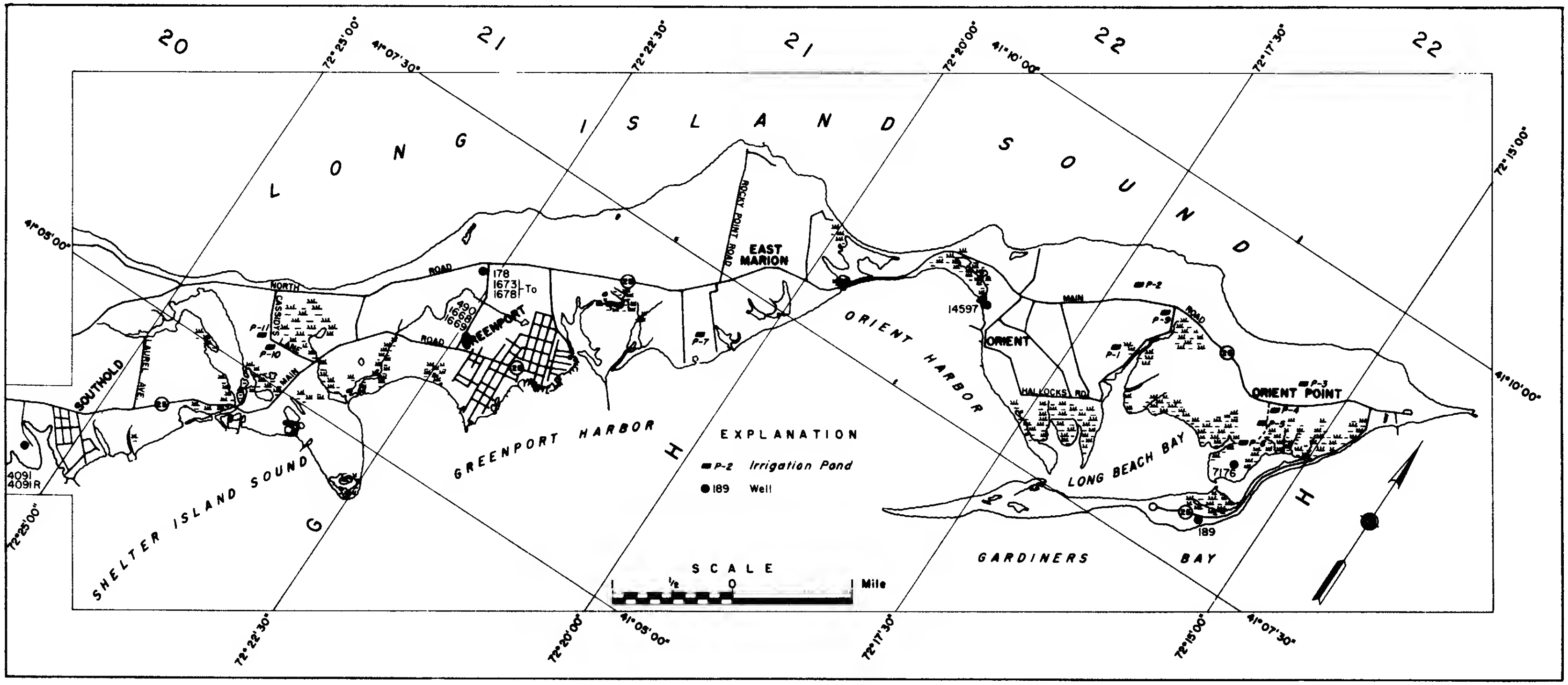

Figure.12.--Map of the eastern part of the Town of Southold showing location of wells and irrigation ponds yielding salty water.

Only three wells in Orient have shown high chloride -- S189 (fig. 12, H-22), 7,600 ppm when drilled in 1935; S7176 (fig. 12, H-22), 1,000 ppm on September 30, 1948, but less on later dates; and S14597 (fig. 12, H-22), 835 ppm on September 20, 1949, and 296 ppm on July 6, 1950. Well S189 is 668 feet deep and reportedly yielded no fresh water when drilled. The well is on a low, narrow bar, which probably contains only a thin lens of fresh water floating on salty water derived from the surrounding sea. Water sampled from S7176, a group of 6 well points driven to a depth of 11 feet, contained so much chloride that in the absence of any other source these concentrations are thought to represent admixture with sea water. At the time of sampling on September 30, 1948, the water table at this site was less than a foot above sea level. The shortest lateral distance to a tidal inlet is about 700 feet. Thus, large irrigation withdrawals during the summer of 1948 probably caused salt water to move in either laterally from the nearby tidal inlet or vertically from beneath, or both. This salty water, when mixed in the well with the fresh ground water, caused chloride concentrations of 1,000 ppm or possibly higher. Well S14597 is about 150 feet from the shore of Orient Harbor, in the village of Orient. Prior to the summer of 1949 a satisfactory water supply was obtained from this well. However, in September 1949 the chloride concentration of the water was 835 ppm, and in July 1950 a second sample contained 296 ppm. The depth of the well is not known, but it seems likely that the high chloride is due to admixture of salty water from the nearby bay or possibly from the underlying salty water.

Greenport-East Marion area

At the village of Greenport, about 4 miles east of Orient, some of the public-supply wells yield water having a detectable salty taste, probably due to the chloride content. Greenport and nearby East Marion, which lie in hydrologic area 2, are virtually surrounded by sea water. The highest place in the area, which contains about 7 square miles, is about 60 feet above sea level, but most of the area is much less than 40 feet above sea level. The water table in unpumped localities has a maximum altitude of about 3 feet above sea level. A sewer system discharges domestic, commercial, and industrial wastes to Long Island Sound, so there is probably little contamination of ground water from these sources.

Station 3 of the village of Greenport water system comprises 6 wells (S1673-78; fig. 12, H-21) about 55 feet deep. These are pumped together, and the mixed water is pumped into the distribution system. Figure 13 shows the monthly variation in the chloride concentration of the water from this station together with the monthly pumpage and monthly precipitation. Figure 14 shows the same data on a daily basis for October 1951. Chloride concentrations of water pumped at this station throughout a period of years have ranged from 123 to 424 ppm, the concentration being highest in the summer when withdrawals are greatest. These concentrations are substantially higher than that (45 ppm) determined in 1932 for the water pumped from well

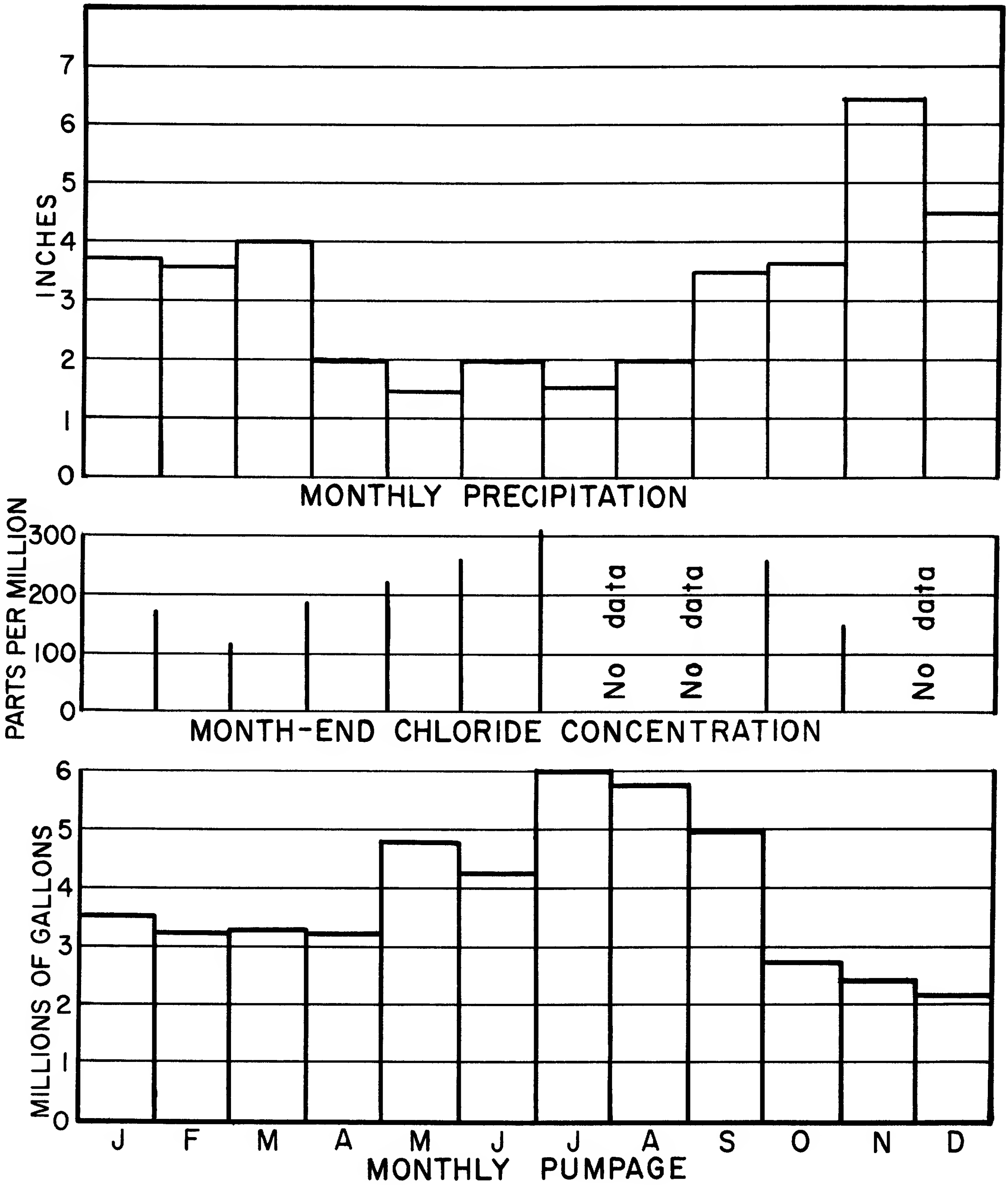

Figure 13.--Variation in chloride content of water pumped at Station 3, village of Greenport Water Supply, with monthly pumpage and monthly rainfall during 1951.

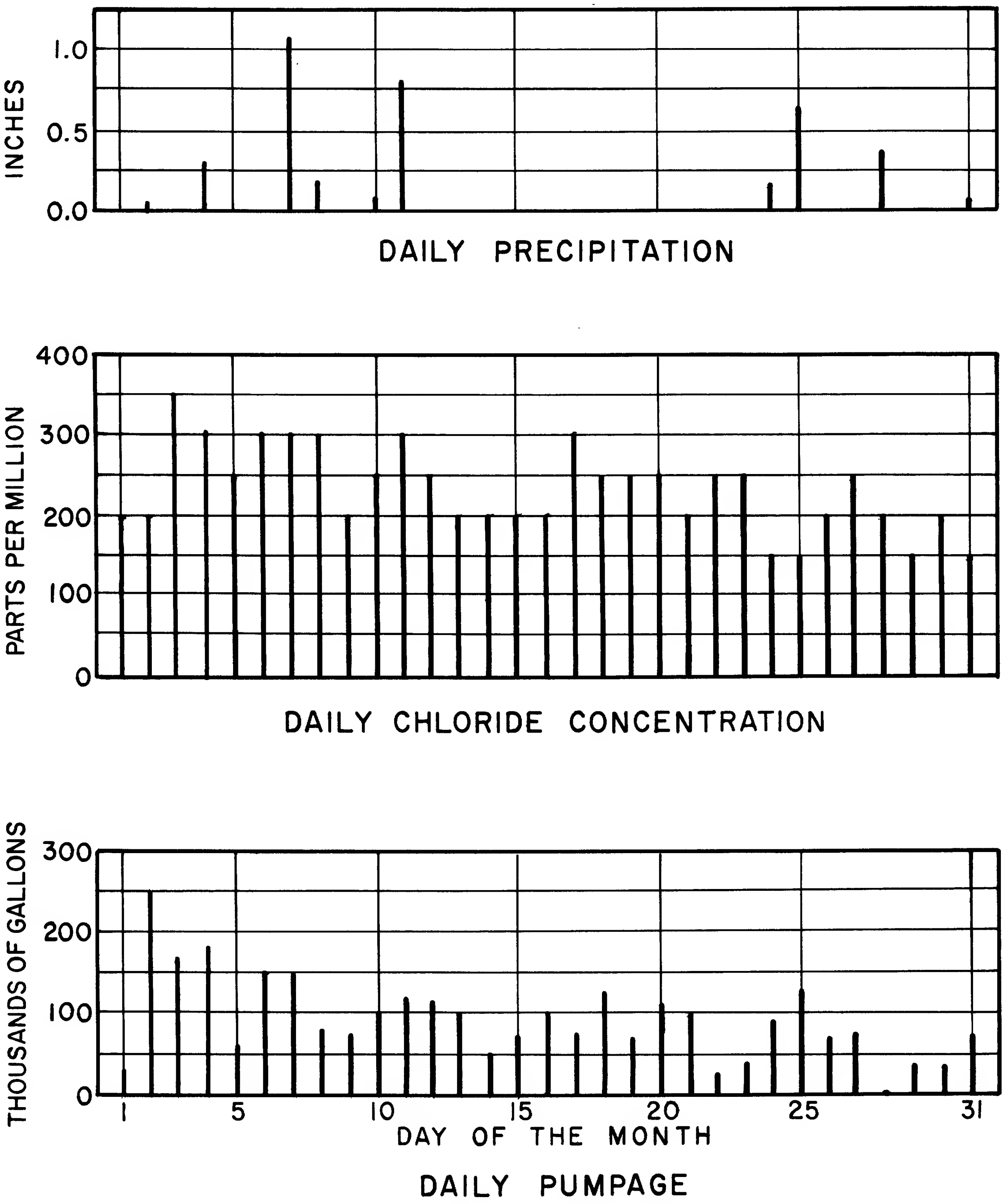

Figure 14.--Variation in chloride content of water pumped at Station 3, village of Greenport Water Supply, with daily pumpage and daily rainfall during October 1951.

S178 at the same site. Extensive spreading of water of lower chloride concentrations during recent years has helped somewhat in reducing the contamination.

Station I has two wells about 35 feet deep that are pumped separately. Water from well S1668 (fig. 12, H-21) has had chloride concentrations ranging from 76 to 94 ppm; and well S1669 (fig. 12, H-21) showed concentrations of 135 and 153 ppm in the summers of 1949 and 1950, respectively. These chloride concentrations indicate an admixture of salty and fresh water. Data obtained during the drilling of test well S490 (V892) a/, drilled 690 feet to bedrock at station I in 1903, indicated salty water at a depth of 225 feet (Veatch, 1906). These data are incomplete, however, and neither the salt-water level nor the actual chloride concentration is known. During the 1940's when the existing wells at Station I (S1668 and S1669) were pumped for brief periods at a rate of 600 gpm, marked and rapid increases in the chloride concentration of the pumped water were observed (Harry Monsell, Village of Greenport Department of Public Works, personal communication). As these wells are about half a mile from any tidewater, this contamination is probably the result of upward movement of underlying salty water. In 1953, when wells S1668 and S1669 were pumped at a rate of about 50 gpm each, they produced water having a chloride concentration ranging from 76 ppm to 153 ppm.

Other Southold areas

Other wells in Southold that are thought to have been contaminated by salty water in nearshore areas are: S4091, Southold (918 ppm); S6059, Peconic (1,600 ppm); and S5475-76, Nassau Point (103 ppm).

Well S4091 (fig. 12, G-20) is about 500 feet from the head of Town Creek, a tidal inlet near the village of Southold. This well, 45 feet deep, is screened in a bed of sand and gravel 60 feet thick, which is underlain by at least 80 feet of clay and sandy clay. According to the driller's report the water beneath the clay and sandy clay is salty. Pumping the well at a rate of about 225 gpm caused salty water to move either upward through the clay or laterally from the inlet. This water, mixing in the well with the fresh water, caused the chloride concentration of the well water to increase steadily from 24 ppm on September 5, 1945, to 918 ppm on July 9, 1952. Owing to the high chloride concentration in the water, the well was abandoned and another well, S4091R, was drilled about 500 feet to the west. The chloride concentration in the water from this newer well was 34 ppm in 1953.

Well S6059 (pl. 1, G-20), 78 feet deep, is approximately 500 feet from a tidal marsh. The log of the well shows 40 feet of fine sand and some clay overlying the 38 feet of sand and gravel in which the well is screened. As the water table at this site is less than 1½ feet above sea level, the well

a/ See well-numbering system described at end of report.

is probably screened in or near the zone of diffusion separating the fresh water and the salty water below. Continued pumping of the well at 350 gpm resulted in a gradual increase in the chloride concentration of the water to 1,600 ppm. Water having this concentration of chloride cannot be used for irrigation in this area, so the well was ultimately abandoned.

Wells S5475-76 (pl. 1, F-20), drilled to a depth of 30 feet, are less than 500 feet from sea water in Nassau Point, an isolated colony of summer homes. The altitude of the water table in the vicinity is not specifically known, but it probably is less than a foot above sea level, and the wells may be screened near the zone of diffusion. Although the draft from these wells is small and the wells are used for domestic supply, the magnitude of chloride concentration (37 ppm, 1948; 103 ppm, 1950) is above the maximum normally expected (25 ppm) and suggests that pumping causes salty water to move into the wells. There is also the possibility that contamination from cesspools has contributed to the chloride concentration. However, no additional data are now available, and further inferences are not possible.

SUMMARY AND CONCLUSIONS

Approximately 83,000 million gallons of usable water are stored in the upper Pleistocene sand and gravel of Southold's shallow ground-water reservoir. The few pieces of available evidence confirm the supposition that this reservoir is underlain by salty water. Owing to the protective influence of the clay of the Raritan formation and the pattern of ground-water movement from the mainland part of Long Island, it is also possible that limited supplies of fresh water may be stored at depths of over 600 feet in parts of the Lloyd sand member. However, very little is known concerning the characteristics of the water in the Raritan formation beneath Southold.

The shallow ground-water reservoir is replenished by the infiltration of precipitation on the Town. During very dry years it is estimated that the replenishment is about 7,000 million gallons annually, or about one-twelfth of the fresh ground water in storage. During other years both replenishment and storage are probably greater. This replenishment is held in storage temporarily, for it is being continuously discharged to the sea by lateral movement of ground water. This lateral discharge, which takes place by spring flow and evapotranspiration near the shorelines and by submarine outflow, may be as much as 6,000 million gallons annually.

As salty water forms both the lateral and the subsurface boundaries of the shallow ground-water reservoir, impairment of the quality of the water through pumping is a constant threat. Serious salt-water contamination has taken place at only a few wells, all of which were near the shore in areas where the water table was less than 2 feet above mean sea level. Perhaps the most serious case of contamination is that of the wells of the village of Greenport's water supply, where chloride concentrations of the well water have been higher than 400 ppm. Controlled pumping of the contaminated wells and mixing the pumped water with water of low chloride content from other wells has kept the water supply potable.

Southold's present (1958) ground-water problem is not so much general sea-water encroachment that would result from general overdraft by pumping of the ground-water reservoir and lowering the water table areally, but rather local contamination resulting from marked lowering of the water table by sustained heavy withdrawals at one well or a cluster of wells. Despite the fact that pumping will create a hydraulic gradient from the salty water to the fresh water, the method and pattern of withdrawals and the subsurface geology largely determine the extent and rate of any encroachment that may take place. Fortunately, withdrawals for irrigation are seasonal and the salty water drawn toward the wells during the summer months may be flushed out during the fall and winter months.

Past experience (1949) indicates that irrigation withdrawals of 4,600 million gallons annually can be made occasionally with impunity, if the present pattern of pumping is observed. As this is only about two-thirds of the average near-minimum replenishment, the allowable withdrawal can probably be doubled safely during most years. In near-shore areas or areas where the water table is close to sea level and the fresh water in storage does not rest on layers of low permeability, even moderate withdrawals may result in sea-water contamination of the reservoir. Previous experience indicates also that it is inadvisable to locate any irrigation pond or well within 1,000 feet of the shoreline or of any embayments containing sea water. Nearshore wells and ponds located according to this rule generally can be pumped intermittently at a maximum rate of about 250 gpm, or about 100 gpm continuously. In the more inland parts of Southold an intermittent pumping rate of 500 gpm has been found satisfactory.

Prior to further development of the ground-water reservoir of Southold, test wells need to be drilled to depths of 200 feet or more to ascertain the lower limits of the fresh-water reservoir, the nature of the underlying salty water, and the physical character of any layers of low permeability that may exist.

Owing to the lack of data, only brief consideration has been given in this report to the relation of trends in precipitation to the volume of fresh ground water in storage. This relationship may prove to be the critical factor governing the allowable withdrawal. Replenishment to and storage in the ground-water reservoir during the period of study may represent optimum conditions. Shrinkage of the volume of fresh water in storage as the result of lowered replenishment for extended periods may cause the base of the fresh-water body to shift upward. Thus, the pattern of withdrawal considered safe under present (1958) conditions may cause a relatively rapid intrusion of salty water under future conditions. On the other hand, the zone of diffusion may lie in material of low permeability and respond very slowly to changes in precipitation. Future problems of sea-water encroachment may appear only gradually.

The data in hand are sufficient to indicate that a future problem may arise and to suggest the relationship of the various factors involved. More detailed data must be collected, however, to substantiate the conclusions that have been made thus far and to permit a more complete analysis of the

geology and hydrology of the area. For example, detailed study of the recharge to the ground-water reservoir necessitates considerable instrumentation for determining precipitation and evaporation. Evaluation of storage in the reservoir requires a more complete appraisal of the hydraulic characteristics of the reservoir and a detailed analysis of fluctuations in ground-water levels. Further knowledge of the physical character of the ground-water reservoir and the occurrence of fresh and salty water requires test holes and possibly additional geophysical exploration. The evaluation of the discharge from the ground-water reservoir at various stages of the water table requires information on the hydraulic characteristics of the reservoir and water-table contour maps. Correlating this discharge with various recharge conditions requires intensification of the water-level-measurement program. Finally, study of the movement and dimensional changes of the zone of diffusion requires detailed sampling of selected wells for chloride content.

WELL-NUMBERING SYSTEM

Wells on Long Island, N. Y., are identified by a numbering system set up by the New York Water Resources Commission. Each well is numbered serially and is prefixed by the initial letter of the Long Island county in which it is located. Thus, for Suffolk County this would be the letter "S", as in the well number S7283. For greater legibility the prefix "S" has been omitted from well numbers shown on plate 1 and in figure 12.

Most wells that were drilled prior to 1932 and that appeared in the early published reports of the Geological Survey have been subsequently assigned numbers under the current system. Thus, for example, the well number S490 is the current number assigned to the well V892, described by Veatch (1906, p. 330).

REFERENCES

Burr, W. H., Hering, R., and Freeman, J. R., 1904, Report of commission on additional water supply for City of New York: New York, Martin B. Brown Co.

Ferris, J. G., 1949, Ground water, Chap. 7 in Wisler, C. O., and Brater, E. F., Hydrology: New York, John Wiley & Sons, p. 198-272.

Gustafson, A. F., and Johnstone, D. B., 1941, Soil and pasture management for Long Island, New York: Cornell Univ. Agric. Expt. Sta. Bull. 755, 44 p.

Hoffman, J. F., 1959, Ground-water utilization, Suffolk County, L. I., N. Y.: Am. Soc. Civil Engineers Proc., v. 85, Separate no. 2080, p. 25-41.

Hoffman, J. F., and Spiegel, S. J., 1958, Chloride concentration and temperature of water from wells in Suffolk County, Long Island, New York, 1928-53: New York State Water Power and Control Comm. Bull. GW-38, 55 p.

Hubbert, M. King, 1940, The theory of ground-water motion: Jour. Geology, v. 48, no. 8, p. 924-926.

Leggette, R. M., and others, 1938, Record of wells in Suffolk County, N. Y.: New York State Water Power and Control Comm. Bull. GW-4, 108 p.

Lusczynski, N. J., and Hoffman, J. F., 1951, The water table as of April 1950 in Southold Township, Suffolk County, Long Island, N. Y.: U. S. Geol. Survey open-file report, 4 p.

Meyer, A., 1944, The elements of hydrology: New York, John Wiley & Sons, 522 p.

Paulsen, C. G., and others, 1940, Hurricane floods of September 1938: U. S. Geol. Survey Water-Supply Paper 867, 562 p.

Perlmutter, N. M., Geraghty, J. J., and Upson, J. E., 1959, The relation between fresh and salty ground water in southern Nassau and southeastern Queens Counties, Long Island, N. Y.: Econ. Geology, v. 54, p. 416-435.

Spear, W., 1912, Long Island sources -- An additional supply of water for the City of New York: New York City Board of Water Supply, 2 vols.

Suter, Russell, deLaguna, Wallace, and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers of Long Island, N. Y.: New York State Water Power and Control Comm. Bull. GW-18, 212 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., p. 519-524.

REFERENCES (Continued)

U. S. Department of Agriculture, 1948, Local marketing report no. 10, 1948, Suffolk County, New York.

Veatch, A. C., and others, 1906, Underground water resources of Long Island, New York: U. S. Geol. Survey Prof. Paper 44, 394 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods; with a section on direct laboratory methods, and bibliography on permeability and laminar flow by V. C. Fishel: U. S. Geol. Survey Water-Supply Paper 887, 192 p.